Integration of Geological, Geophysical and Remotely Sensed Data Over a Part of Singhbhum Shear Zone (Bihar) -An Attempt to Develop a Mathematical Model for Lineament Extraction and Mineral Targeting

DISSERTATION

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BY

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INTEGRATION OF GEOLOGICAL, GEOPHYSICAL AND REMOTELY SENSED DATA OVER A PART OF SINGHBHUM SHEAR ZONE (BIHAR)- AN ATTEMPT TO DEVELOP A MATHEMATICAL MODEL FOR LINEAMENT EXTRACTION AND MINERAL TARGETING

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GLOSSARY

BIL	:	Band Interleaved by Line
CCT	:	Computer Compatible Tape
CRC	:	Colour Ratio Composite
ERS	:	European Remote Sensing Satellite
FCC	:	False Colour Composite
FFT	:	Fast Fourier Transform
IIPS	:	IPAD Image Processing System
IOG	:	Iron Ore Group
IR	:	Infrared
IRS	:	Indian Remote Sensing Satellite
LISS	:	Linear Imaging Self-Scanning (Sensor)
Ma	:	Million years
MOS	:	Marine Observation Satellite (Japan)
MSS	:	Multli-Spectral Scanner
OPD	:	Optical Density
SSZ	:	Singhbhum Shear Zone
TIR	:	Thermal Infrared
TM	:	Thematic Mapper
Vis.	:	Visible
VTIR	:	Visible and Thermal Infrared Radiometer

SUMMARY

Remotely sensed data over a part of Singhbhum shear zone (SSZ) have been analysed, along with the available geological and geophysical data and an attempt has been made to correlate the remotely sensed data with the surface geology, tectonics and mineral/ore occurrence of the area, by developing a mathematical model.

Standard methods of visual interpretation and digital image processing have been followed during the course of study. Lineament analysis was carried out visually through LANDSAT TM and IRS-1A LISS II data and digitally by LANDSAT MSS and MOS-1 VTIR CCT's. Directional filtering, highpass filtering and FFT have also been attempted and corresponding filtered images were also obtained. Ratio images of MSS data with different combinations were also obtained and False Colour Composite (FCC) and Colour Ratio Composite (CRC) of these bands/ratios were generated.

The lineament analysis of the study area highlights the tectonic activity of this important mineral belt. The major alignment of the linears and the course of Subarnarekha river depicts that the area is under continued tectonic activity.

Bivariate correlation analyses between optical density on one hand and gravity, magnetic and lineament data respectively on the other, have been

attempted, along with the multivariate correlation analyses taking all the four parameters i.e. optical density, gravity, magnetic and lineament percentage together.

It is found that the patterns of isolines of correlation coefficient correspond to the geophysical anomalies and tectonic set-up as well as known mineral/ore occurences. The patterns of correlation coefficient contours interpreted in terms of mineral occurrences and tectonic set-up of the area, and these indicate a strong possibility that it can be used in inferring new probable zones of mineral/ore occurrences. Also, the tectonic deformations along the Singhbhum microplate can be interpreted broadly which explains the development of Singhbhum shear zone during its multiphase orogeny.

This study has provided a quantitative approach for using remotely sensed data along with other geological/ geophysical data for the prediction of probable mineral/ore prospects in an area.

1.0 INTRODUCTION

The Singhbhum shear zone (SSZ) occupies an important position in the Indian geological and tectonic history. Singhbhum thrust zone, Singhbhum orogenic belt, and copper belt thrust are synonymous terms to Singhbhum shear zone, and have been used by different workers at different times. The belt has attracted many geoscientists from within and outside the country, for its complex geological nature (Sarkar, 1982). Scroes of eminent workers including Dunn (1929, 1937), Sarkar and Saha (1962, 1977), Saha (1970), Bhattacharyya et al. (1976), Mukhopadhyay et al. (1975) Naha (1965), Sen Gupta and Datta (1978), Gupta et al. (1981) have worked extensively in this important geologically active belt.

The study area constitutes a part of Singhbhum shear zone, falling between latitudes 22° 15'N to 22° 45'N and longitudes 86° 10'E to 86° 40'E.

The Singhbhum shear zone extends for about 200 kms with an arcuate disposition, (northen convexity) along the southern edge of the Singhbhum anticlinorium (Dunn and Dey, 1942). The major part of the shear zone lies in Bihar, but it has been reported that it extends up to Mayurbhanj district in Orissa (Rakshit and Swaminathan, 1985). The width of the shear zone is not uniform, and varies over its entire length. In westren

Singhbhum, the zone is more than 25 kms. wide, where three major slices are recognised; these slices are tightly packed up together in central Singhbhum in a narrow zone of about 1 km. only. It again widens to more than 5 kms. in eastern Singhbhum and the adjoining part of Mayurbhanj district of Orissa (Sarkar, 1982; Bose, 1991).

The belt is also very important from the economic point of view, as vast deposits of copper ores occur in this area, besides iron ores, micas, refractory minerals and radioactive minerals e.g. uranium, thorium etc. (Gokhale and Rao, 1973). The country's only uranium mine (Jaduguda) is located along this belt. The area is also under active exploration for economic minerals. The shear zone schistose rocks acts as hosts for mineralization and are bounded by two prominent lineaments, probably marking the limitation of the shear zone. The shear zone has been intersected by a number of NNE-SSW to NE-SW lineaments, where concentration of known ore-bodies occurs. Therefore, such intersections may help as a guide for the hidden ore/mineral occurrences.

Moreover, the SSZ is tectonically active due to the collision of two different plate margins namely, Singhbhum microplate and Chotanagpur microplate and their subsequent submergence and developed shear in the eastern part near Ghatsila. Different structural and geological models have already been attempted to explain the complex nature of these plate motions and their subsequent impact over the Singhbhum orogeny, and geological studies are still continuing to understand the activities of different plates in the recent era (Sarkar, 1982; 1988). In this context, a mathematical correlation/model has been attempted here to classify the SSZ in terms of its past tectonic activities over different zones.

The area has been extensively studied for its geology, geophysics, tectonics and structural history, and geological mapping and exploration methods, leading to new thoughts and ideas for the geological problems of the region. However, correlation of different sets of data with the remote sensing data, to develop an integrated approach, for mineral/ore prospects and lineament analysis of this economically and strategically important region, is yet to be established (Gupta, 1992). Though a qualitative study of the usage of remotely sensed information along with other geological/geophysical information for generalised discrimination of geological units in SSZ has been reported by several authors including Rakshit and Swaminathan (1985), Gupta (1992).

However, an integrated technique has been developed and applied recently by Mitra et al. (1985) over a part of the Cambay basin, covered with alluvial plains and recent sediments, for the prediction of hydrocarbon-bearing structures. Very recently, Gunasekaran et al. (1992) have carried out integration of geophysical data with LANDSAT TM data in north-eastern part of the country for the hydrocarbon exploration. They have also emphasised the need of integrated approach for the mineral exploration as well.

Remote sensing data have been used recently by Ganzorig et al. (1991) to confirm the exitsing ore bearing areas and further explore the prediction of probable mineral/ore bearing zones in parts of Mongolia.

Figure 1 shows the block diagram illustrating various components at the earth's surface that may contribute to remote sensing data.

Accordingly, a study of this area (SSZ) is carried out with a view to establish a quantitative approach to the utilisation of remotely sensed data for mineral targeting as well as lineament analysis.

This particular study projects the possibilities of a quantitative approach to the problem by developing and applying a mathematical model to correlate the remotely sensed data with the available geological, geophysical and topographic data so that the degrees of correlation can be better established. The importance of these studies rests in the fact that such an objective correlation can ultimately lead to the prediction of probable mineral/ore deposits in unknown areas as well as bring out the information on the tectonic set up of the region, primarily through remote sensing techniques.

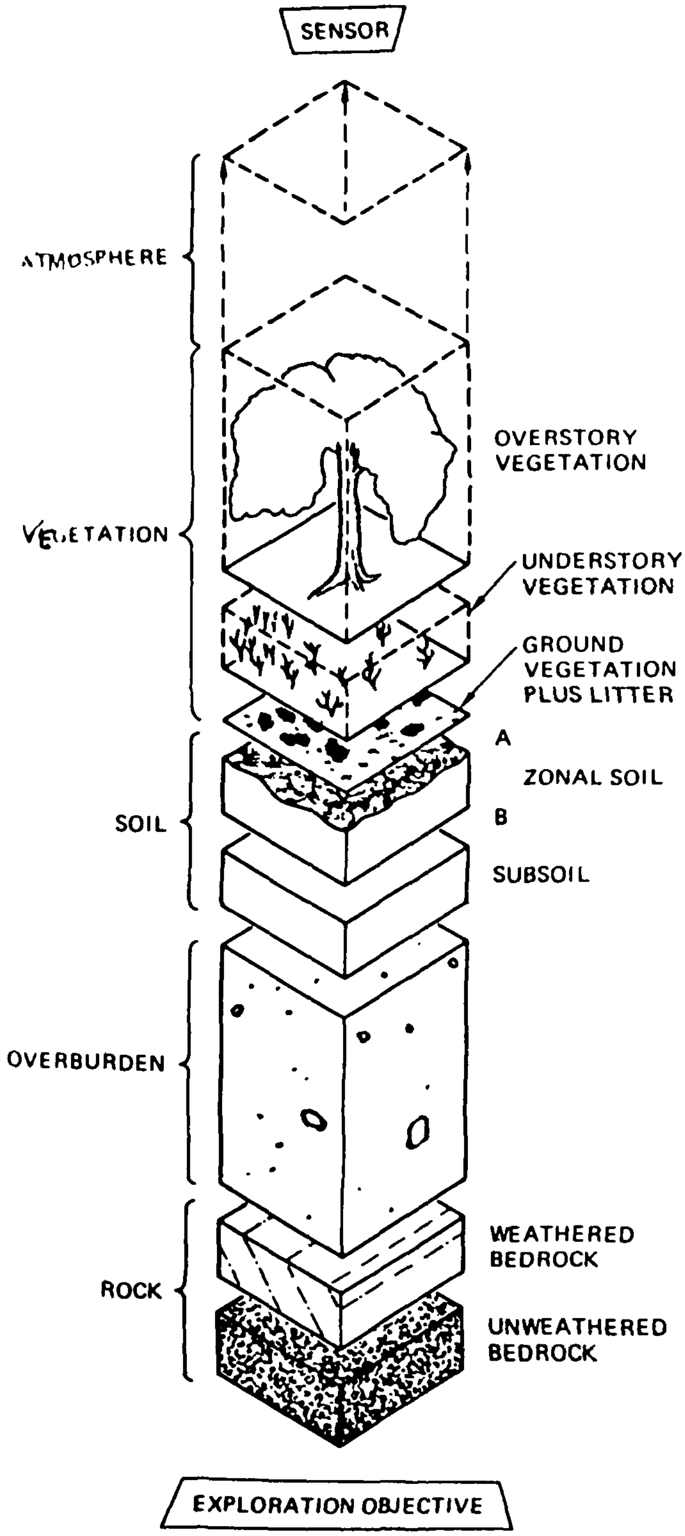


Fig.1: Block diagram illustrating components at the earth's surface that contribute to remote sensing data (after Abrams, 1984).

2.0 GEOLOGY AND STRATIGRAPHY OF SINGHBHUM SHEAR ZONE

Singhbhum is an area of complex geology, located in the eastern part of Indian peninsula, approximately between latitudes 21° 0' to 23° 15'N and longitudes 84° 0' to 87° 30'E. It is characterised by superposed polyphase deformations, metamorphism and igneous activities. Although extensive research work has been done in this part of the Indian shield that contributed to the unveiling of many of the complexities, but, at the same time, it has raised many controversies regarding its stratigraphic and tectonic classification (Sarkar and Chakraborty, 1982; Desikachar, 1974). Figure 2 shows the geology of the area.

Lithologically, the area consists of the rocks of Singhbhum, Kolhan, Chaibasa, Dhanjori and Dalma groups along with Precambrian metamorphites of iron ore. Singhbhum granite and Kuilapal grantie occupy a large area. Different rock types present in the area are high and low grade mica schists, quartzite mica schists, conglomerate, sandstone, metalavas, granite and gneisses and ultrabasic intrusives. Geologically the area is quite complex and interesting, so far as its stratigraphic status, variations in lithology, tectonic evolution and genesis and localisation of ore bodies is concerned (Rakshit and Swaminathan, 1985).

There are two broad views regarding the stratigraphic and tectonic classification of the area. According to one school, the rocks of the north and south

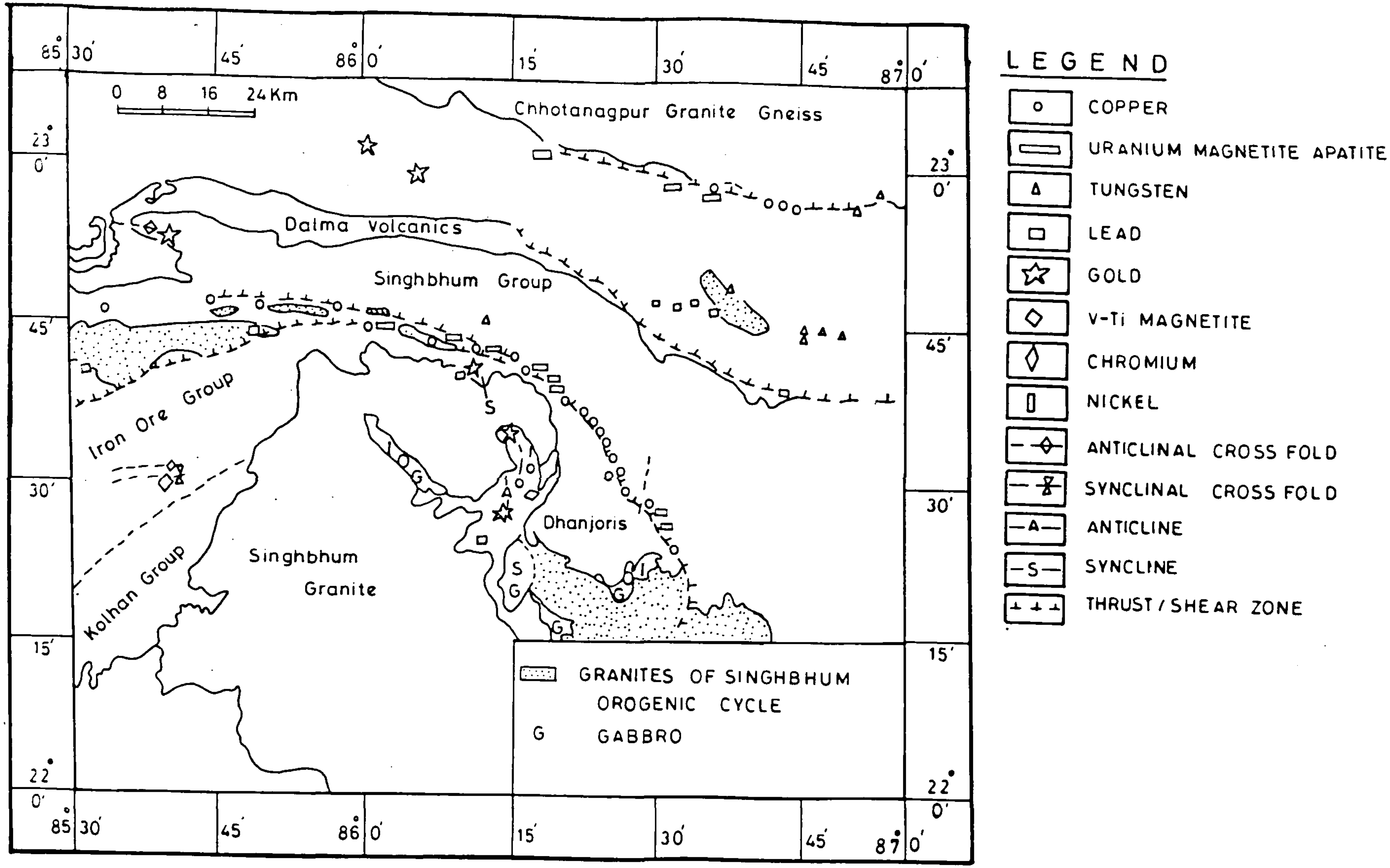


Fig.2: Geological map of Singhbhum region showing distribution of metalliferous deposits (after Dunn, 1929).

Singhbhum, inspite of their apparent and metamorphic contrasts, belong to one broad stratigraphic unit, whereas the other school has classified the rocks into two stratigraphic and orogenic belts. However, both schools believe that the structural and metamorphic contrasts of the north and south were brought about by large scale horizontal displacement of the rocks along a prominent E-W trending thrust belt (Mukhopadhayay, 1976).

Dunn (1929) and Dunn and Dey (1942) classified the Precambrian rocks of Singhbhum into the following sub-divisions :

Iron Ore Series	---	**Iron Ore Stage**
	---	**Chaibasa Stage**

According to them, the rocks of north Singhbhum belong to both stages, and those of the south Singhbhum to the Iron ore stage only. The rocks of the north have an E-W regional strike and those of the south have NNE-SSW. They also concluded that juxtaposition of these rocks was caused by a prominant thrust, named as 'Copper belt thrust'.

A revised stratigraphic sequence of Singhbhum **(Table-I)** on the basis of stratigraphic and structural studies, coupled with geochronological data have been suggested by Sarkar and Saha (1977) and Sarkar et al. (1979). In their revised classification, the rocks of north

TABLE-I

Stratigraphic sequence of the Precambrian rocks of Singhbhum

(after Sarkar and Saha, 1977 and Sarkar et al., 1979)

south of copper belt thrust	**north of copper belt thrust**
--------------end of Singhbhum orogenic cycle------------------ (850 Ma)	
Granite gneiss, granophyres, gabbro-anorthosites	Granites and granophyres
Ultrabasics	
Kolhan group (metasedimentaries) (1500-1600 Ma)	Dalma lava ---------overlap---------
Dhanjori formation : volcanics and sediments	Singhbhum group: Dhalbhum form., Chaibasa form.
----------------------Unconformity------------------------------	
--end of Iron Ore orogenic cycle---- (2900-3000 Ma)	
Singhbhum granite	
Epidiorite	
Iron Ore group: sedimentaries and volcanics (slightly metamorphosed)	
------------Unconformity----------	
--end of older metamorphic cycle--- (3200 Ma)	
Granitic and basic rocks	
Older Metamorphic group: moderate to high-grade metasedimentaries and basic intrusives	

Singhbhum, i.e. 'Singhbhum group' and the 'Dalma volcanics' are placed much younger than the 'Iron ore group' rocks of south Singhbhum, both evolving into two separate orogenic belts (closing at 850 Ma and 2900-3000 Ma respectively). Large scale N-S displacements of the rocks along the thrust belt have brought these two orogenic belts in an intersecting disposition (Sarkar, 1963; Sarkar, 1982; Sarkar and Srivastava, 1982).

3.0 STRUCTURAL AND TECTONIC HISTORY

The most conspicuous feature of the region is the tortuos pattern of the Dalma epidiorites, which extends over a distance of about 200 kms., forming a spectacular fold closures facing east and west within a general protrusion towards west. Dunn (1929) had suggested that this outcrop pattern is caused by the westerly plunging folds of the Singhbhum 'geoanticline' ('Singhbhum anticlinorium' by Sarkar and Saha, 1962). The anticlinorium has been thrusted over the rocks to the south along a prominent shear zone, termed as 'Copper belt thrust' (now Singhbhum shear zone). The thrust planes have an overall northerly dip, but regionally they form a sweeping curve, convex northward (Sarkar, 1982). According to Sarkar (1963), this shear zone separates two orogenic belts - the younger Singhbhum orogenic belt in the north, striking E-W, and the older Iron ore orogenic belt in the south, striking NNE-SSW. Figure 3 shows the structural and tectonic map of the region.

Sarkar (1982) has described four major phases of deformation in the area. All the four phases have left their distinctive imprints on the geology and structure. Moreover, all the four fold systems and the accompanying planer and linear structures are not equally developed all over the belt, and vary regionally in orientation and angular relations.

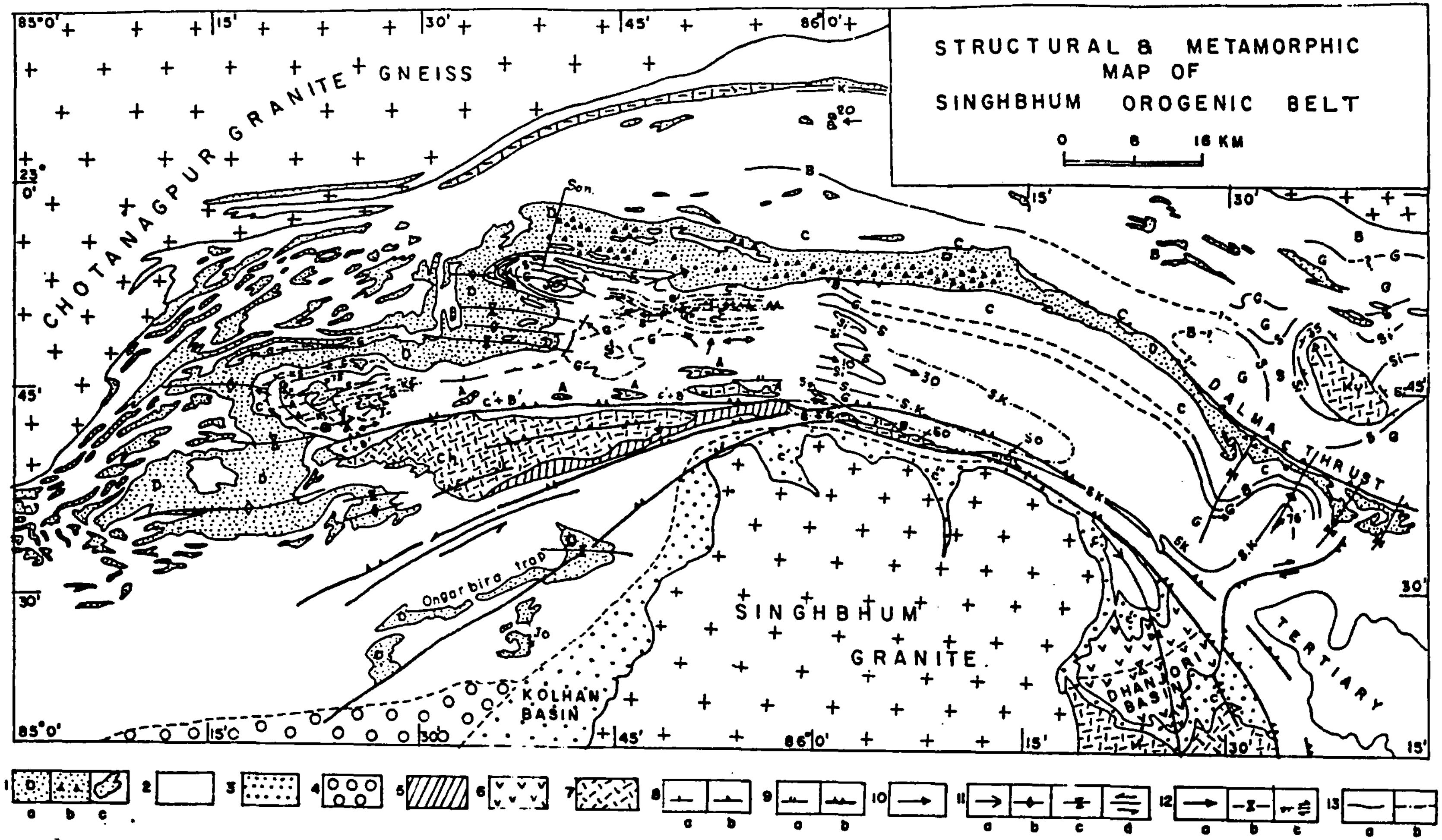


Fig. . Structural and metamorphic map of the Singhbhum orogenic belt . *1a* = Dalma ophiolite, *1b* = Dalma ophiolite with ultramafic fragments, *1c* = exotic masses, *2* = flysch, *3* = molasse, *4* = platform sediments, *5* = basic and ultrabasic rocks of Singhbhum thrust zone, *6* = Dhanjori lava, *7* = granitic and migmatitic rocks: *A*—Arkasani granophyre, *Ch*—Chakradharpur granite gneiss, *Ku*—Kuilapal granite (migmatite), *M*—Mayurbhanj granite, *So*—Soda granite, *T*—Tebo migmatite, *8a* = generalised S_2, *8b* = early thrust, *9a* = generalised S_3, *9b* = late thrust, *10* = F_1 axis, *11a*. F_2 axis, *11b* = antiformal axial trace of F_2, *11c* = synformal axial trace of F_2, *11d* = sinistral F_2 shear, *12a* = F_3 axis, *12b* = synformal axial trace of F_3 *12c* = composite dextral shear and overthrust of F_3, *13a* = M_1 isograd, *13b* = M_3 isograd. *C* = chlorite z., *B* = biotite z., *G* = garnet z., *S* = staurolite z., *K* = kyanite z., *Si* = sillimanite z. (letters with dash represent corresponding minerals of M_3). *Jo* = Jojohatu, *O* = Ongarbira trap, *Son* = Sonapet valley. *T* = Tebo.

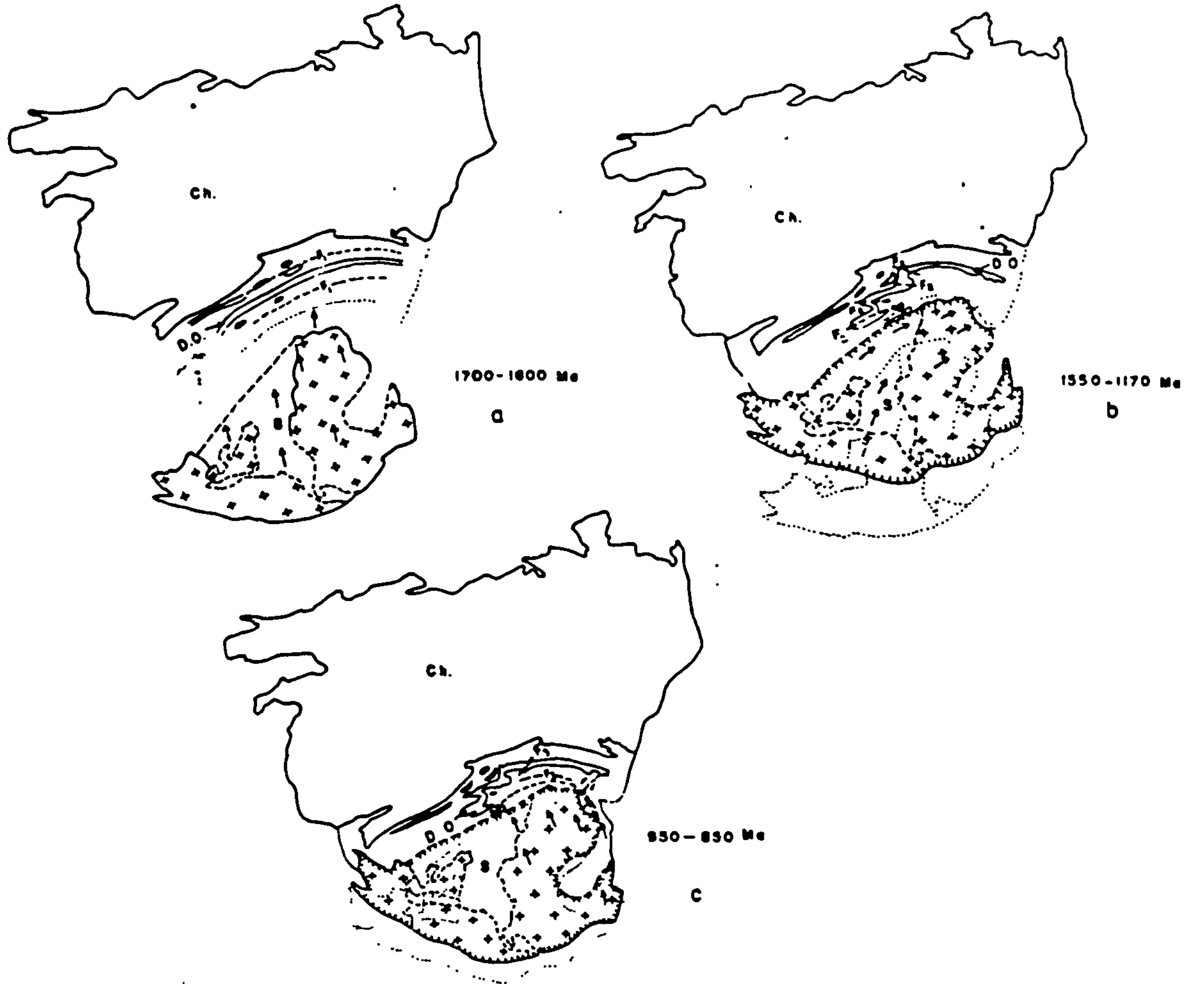
Fig.3: Tectonic and structural map of the region (after Sarkar, 1982).

The characters of the shear zone, such as geological facies, structural and metamorphic history etc. suggest that they are closely related to Phenorozoic mountain belts of the world, that are considered as well-known examples of continent-continent collision (Dewey and Bird, 1970; Burret, 1972; and, Bird and Toksoz, 1975).

The Singhbhum plate collided with the Chotanagpur plate during 1600-2000 Ma, which led to the tectonic emplacement of Dalma ophiolite belt. The Singhbhum plate rotated clockwise during 1170-1550 Ma, and obduction of the continental lithosphere of this plate occurred during 850-1000 Ma ago (Sarkar, 1982). Figure 4 shows the movement of the two plates during their tectonic cycle.

3.1 TECTONIC EVOLUTION IN THE LIGHT OF PLATE TECTONICS

It is earlier described that Singhbhum orogenic belt is an example of continent-continent collision. So far as the plate tectonics view is concerned, the model proposed by Sarkar (1982), explained the detailed geologic and tectonic evolution of the area. His model differs from the intraplate subduction model developed earlier by Sarkar and Saha (1977). They interpreted the Singhbhum thrust zone (shear zone) as the convergent plate junction and did not consider the implications of the Dalma ophiolite, details of structural and metamorphic data and different sedimentary facies from the plate tectonics point of view. Sarkar (1982), in his model has used the terms Singhbhum microplate for



Diagrams illustrating successive positions and movement directions of the Singhbhum microplate relative to Chotanagpur microplate and major tectonic developments . The dotted lines indicate the precedent positions of the Singhbhum microplate. *Ch* = Chotanagpur microplate, *S* = Singhbhum microplate. *D.O.* = Dalma ophiolite. (a) At 1700–1600 Ma, (b) at 1550–1170 Ma, (c) at 950–850 Ma.

Fig.4: Map showing movements of the two plates in relation to plate tectonics theory (after Sarkar, 1982).

Singhbhum craton with the continental crust underlying the plateform sediments, and Chotanagpur microplate for the Chotanagpur granite gneiss complex, occupying a vast terrain. He has also determined relative movements of the Singhbhum microplate, while arbitrarily fixing the Chotanagpur block. In addition he has distinguished three major cycles of plate motions.

During the first cycle which took place between 2000-1600 Ma ago, the Singhbhum plate moved northward and collided with the Chotanagpur plate, which led to the tectonic emplacement of the Dalma ophiolite belt, development of first stage folds and thrusts. The Singhbhum plate rotated clockwise towards the NE during the second cycle, between 1550-1170 Ma ago, which led to the development of sinistral shear zone. The third and last cycle took place around 1000-850 Ma ago, during which obduction of the continental lithosphere of Singhbhum plate occurred and led to the development of Singhbhum thrust zone (shear zone). Figure 4 shows the movements of the plates during the three cycles of motion.

4.0 DATA SOURCE AND AREA OF INTEREST

The Singhbhum shear zone occupies an important position regarding its geology, stratigraphy, tectonics and economic point of view. The major part of the Singhbhum shear zone lies in Bihar, but it extends up to Mayurbhanj district of Orissa. The study area of interest covers latitudes 22° 15' N to 22° 45' N and longitudes 86° 10' E to 86° 40' E.

Geologically, the Singhbhum shear zone is a part of Singhbhum craton, and is an active tectonic feature in eastern India. Its tectonic activity has left many impact on the structure and surface geology of the area, such as few promient faults, interpreted from LANDSAT MSS and IRS-IA images.

The geophysical anomalies in the region also vary from the lowest level to the highest one. The gravity values in the area varies from 0 mgal to -40 mgals, representing many gravity highs and lows.

The magnetic data over the area of interest is sparce, but the general trends of the magnetic anomalies are E-W, three major magnetic linears trending E-W, have been reported by Banerjee (1981). The minor linears in the area also follow the similar trends.

Topographically, the area is active. The northern and south western part is rugged, and hilly terrains are conspicuous, where the elevation reaches as much as above 600 m. The central and south-eastern part is gentle, along the foothills and alluvial plains, where elevation reaches at a minimum of 70 m. The details of geophysical data have been given in the subsequent chapters. For the present study the following inputs have been collected and subsequently used for the generation of data and final analysis. (IIPS Program Library, 1979). The details of different bands of various sensors are given in Appendix-A.

LANDSAT MSS : Computer Compatible Tape (CCTs) are used, path-row (139-45), dated 15th March, 1986. All the four bands namely, 4, 5, 6 and 7 were used for the study.

LANDSAT TM : Hard copy print of the complete scene is used for visual interpretation of regional linears. CCTs of 4th January, 1988 path-row (140-44) have been used with bands from 1 to 7. Band 6 containing TIR data was used for regional linears extraction. Scale 1 : 1 million

IRS-1A : FCC of bands 2, 3 and 4 of LISS II of 5th December, 1989, path-row (20-52) was selected and major and minor linears were extracted by visual interpretation. Scale 1 : 1 million

MOS-1 : Visible and TIR bands of VTIR were used for extraction of regional linears.

BOUGUER ANOMALY MAPS :	Small scale gravity maps, obtained from recent literature have been used.
MAGNETIC ANOMALY MAPS :	Regional magnetic and aeromagnetic anomaly maps have been used as an input to the present data set.
RELIEF DATA :	Primarily obtained from the Survey Of India toposheets. Scale 1 : 50 000 and 1 : 2 50 000 .
GEOLOGICAL MAPS :	Different geological maps have been used to obtain geological information related to mineral deposits, uranium and thorium occurrences, heat flow and tectonic set up of the area. Scale 1 : 50 000 and 1 : 2 50 000
SURVEY OF INDIA MAPS :	73 J, on the scale of 1 : 2 50 000 and 73 J/6, 73 J/10, 73 J/11 on scale 1 : 50 000.

5.0 GEOPHYSICAL DATA

5.1 GRAVITY DATA

Regional gravity surveys and their relational behaviour with other geophysical data in the area were first carried out by Qureshy (1970) and by Qureshy and Warsi (1980) which have brought out detailed information on some major structures present in the area.

The gravity field in the area has been considerably influenced by the history of iron ore geosyncline starting from about 3200 Ma. including sedimentation, volcanism, basic and ultrabasic intrusions, granitic intrusions of batholithic dimensions, differentiated granites as well as thrust movements of major dimensions (Verma et al., 1984).

The Bouguer anomaly map of the region is shown in Fig. 5. The anomaly map bears a good correlation to the surface geology. There are two prominent contour trends, an E-W trend in the northen part prevailing over the Singhbhum group of rocks and the Dalmas, and a N-S trend over IOG, Dhanjori group and Simplipal basin.

The map depicts several gravity highs and lows, which are in general, caused by the variation of density of the near surface rock formations. The Iron ore

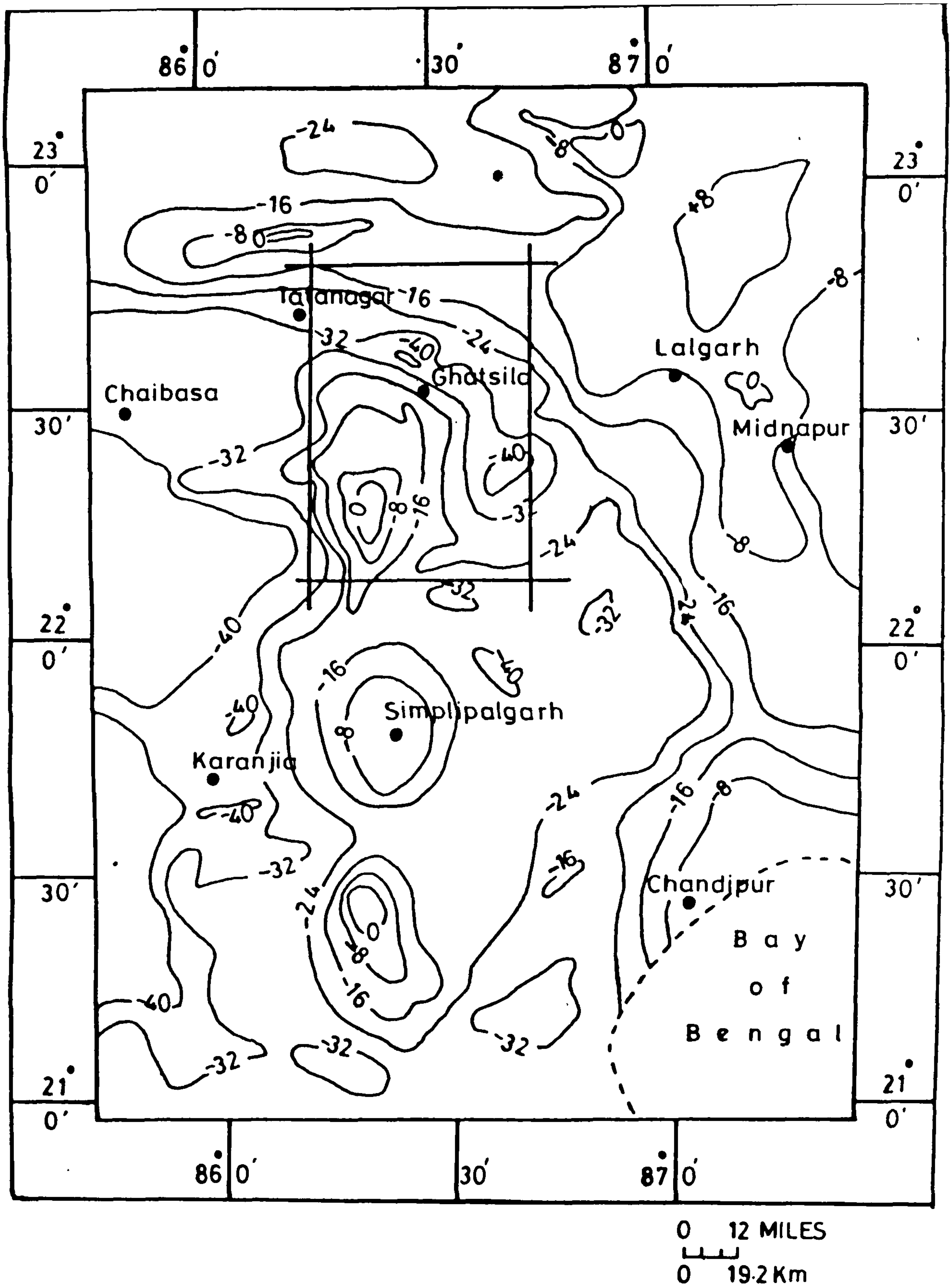


Fig.5: Regional Bouguer anomaly map of the study area (after Verma et al., 1980).

CONTOUR INTERVAL ~ 8 mgals

group (IOG) consisting mostly of iron bearing sediments, and rocks of Singhbhum group are of higher density than the basement complex and hence cause the gravity highs (Verma et al., 1984).

Nearly all the gravity highs in the area are characteristically associated with synclinal structures filled with metasedimentary formations interbedded with basic intrusives in the form of lavas or gabbro anorthosite masses. The gravity highs over IOG, Singhbhum group, Dhanjori and Simplipal basins support this view.

All the gravity lows in the area (as observed over the Singhbhum granite and its margins) are due to the granitic masses, sometimes associated with anticlinal structures, which suggest their intrusive nature. The granitic bodies present in the area varies in their density from one locality to another and hence cause gravity lows of varying amplitudes (Verma et al., 1978).

5.2 MAGNETIC DATA

The area has received little attention regarding its magnetic data, and only a few workers have been able to expose it. Verma et al.(1980) have reported that Chaibasa schists and phyllites are highly susceptible, whereas the Singhbhum granite has low magnetic susceptibility and the Dalmas have still lower magnetic susceptible anomalies.

Banerjee (1981) has described as many as three major lineament depicting shears in Singhbhum. The outcrops of Singhbhum formation to the south of Dalmas are associated with strong magnetic anomalies, oriented in E-W direction.

Perumal et al. (1985) carried out an integrated approach to multisensor airborne remote sensing and LANDSAT studies in Singhbhum-Uranium-Copper belt. The aeromagnetic contour map developed by them showed excellent correlation with the lithology and structure. Figure 6 shows the magnetic anomaly map representing regional magnetic trends over a part of Singhbhum shear zone. The trends of the magnetic contours remarkably coincide with the structural trend lines of volcano-sedimentary sequences. The linear arcuate Dalmas and Singhbhum shear zone formation were clearly brought out by high magnetic fields. Perumal et al. (1989) have also carried out lineament analysis using LANDSAT data and their subsequent correlation with aeroradiometric and geophysical data over a part of Indian peninsula.

Chowdhury et al. (1989) have concluded that the gravity lineaments and the magnetic lineaments have the similar trends i.e., in the northen part E-W trending lineaments are predominent, whereas, in the southern part, over the Singhbhum shear zone, N-S oriented trends are predominent. However, three E-W trending ones are very prominent in the area out of which one follows the alignment of the Singhbhum shear zone. The N-S lineaments occur to the west of the area (Fig. 6). They were also able to interpret few faults across the magnetic trends.

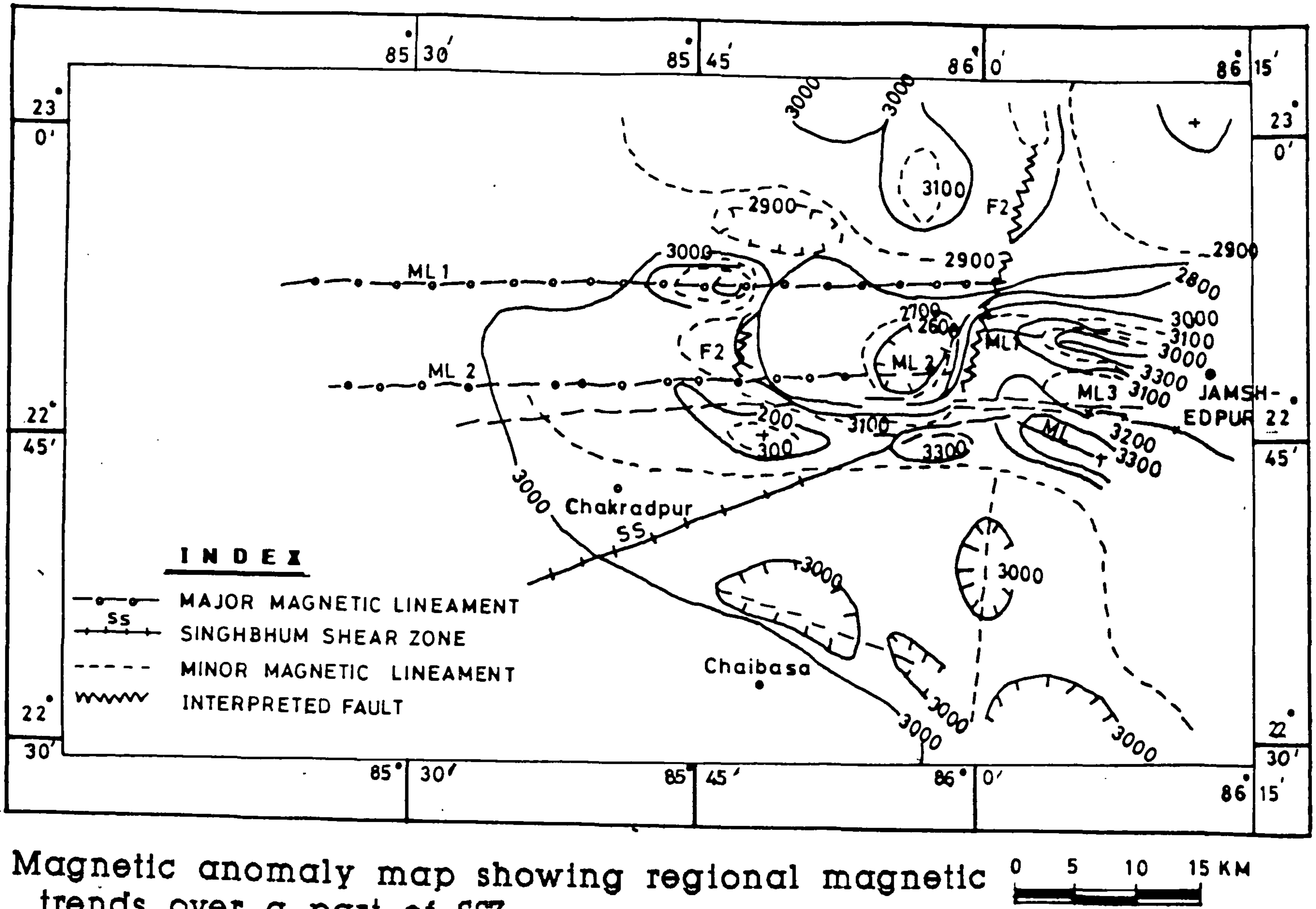


Fig.6: Magnetic anomaly map showing regional magnetic trends over a part of SSZ.

Recently, Dasgupta et al. (1991) have distinguished geological structures of varying magnetisation with the help of aeromagnetic images. They have also reported an E-W trending linear along the southern boundary of the Dalmas, showing a considerable magnetic susceptibility contrast between the Dalmas and the Singhbhum group. This is corroborated by the occurrence of highly magnetic Dhalbhum formation to the south of the Dalmas.

Singhbhum craton, occuring to the south of the Chaibasa formation, exhibits a weak regional magnetic field. The magnetic features present below the shear zone along the boundary of the granitic mass are associated with N-S faulting and possibly point out the areas of occurrence of base metals and allied deposits (Dasgupta et al., 1991). Many of the present mining areas are operating along the above mentioned part of granitic boundary.

5.3 LINEAMENT ANALYSIS

A lineament is a regional scale linear or curvilinear feature, pattern or change in patterns that can be identified in a data set and attributed to a geological formation or structure (Parson and Yearley, 1986).

Hobbs (1904) had introduced the term 'lineament' to characterise the relationships among " (1) crest of ridges or boundaries of elevated areas, (2) the drainage lines, (3) coast lines, and (4) boundary lines of formations, petrographic rock types, or lines of outcrops."

In recent years, dévelopments in remote sensing and, in particular, the large-area, small scale imagery obtained from LANDSAT, IRS, SPOT, and ERS satellites, have led to an upsurge of interests in lineaments, which are particularly clearly visible both from above and at regional scales. However, there has been a difference of opinion over the reliability in identification of lineaments and hence the validity in their interpretation (Moore and Waltz, 1983; Wheeler, 1983; Wise, 1977, 1982, 1983).

The study area constitutes of a part of LANDSAT TM scene path-row (140-44) of 4th January, 1988. For the interpretation of regional linears, thermal infrared (TIR) band (B-6) of LANDSAT TM was selected and all the major and minor regional linear patterns were extrapolated as shown in Fig. 7.

Visual interpretation of linears has also been carried out over IRS-1A, path-row (20-52), area falling in LISS II B1 subscene. For that a diapositive of band 2, 3 and 4 was selected and all the major and minor linears were extracted, besides some other geological and geomorphological units. The linears are better interpreted on IRS image than to LANDSAT TM thermal IR image. There is a marked difference between the two images, that IRS-1A image (of 5th December,1989) clearly depicts a prominent water body engulfed between confluence of NW-SE pairs of linears, but LANDSAT TM image (of 4th January,1988) do not show any such feature (Figs. 7 and 8).

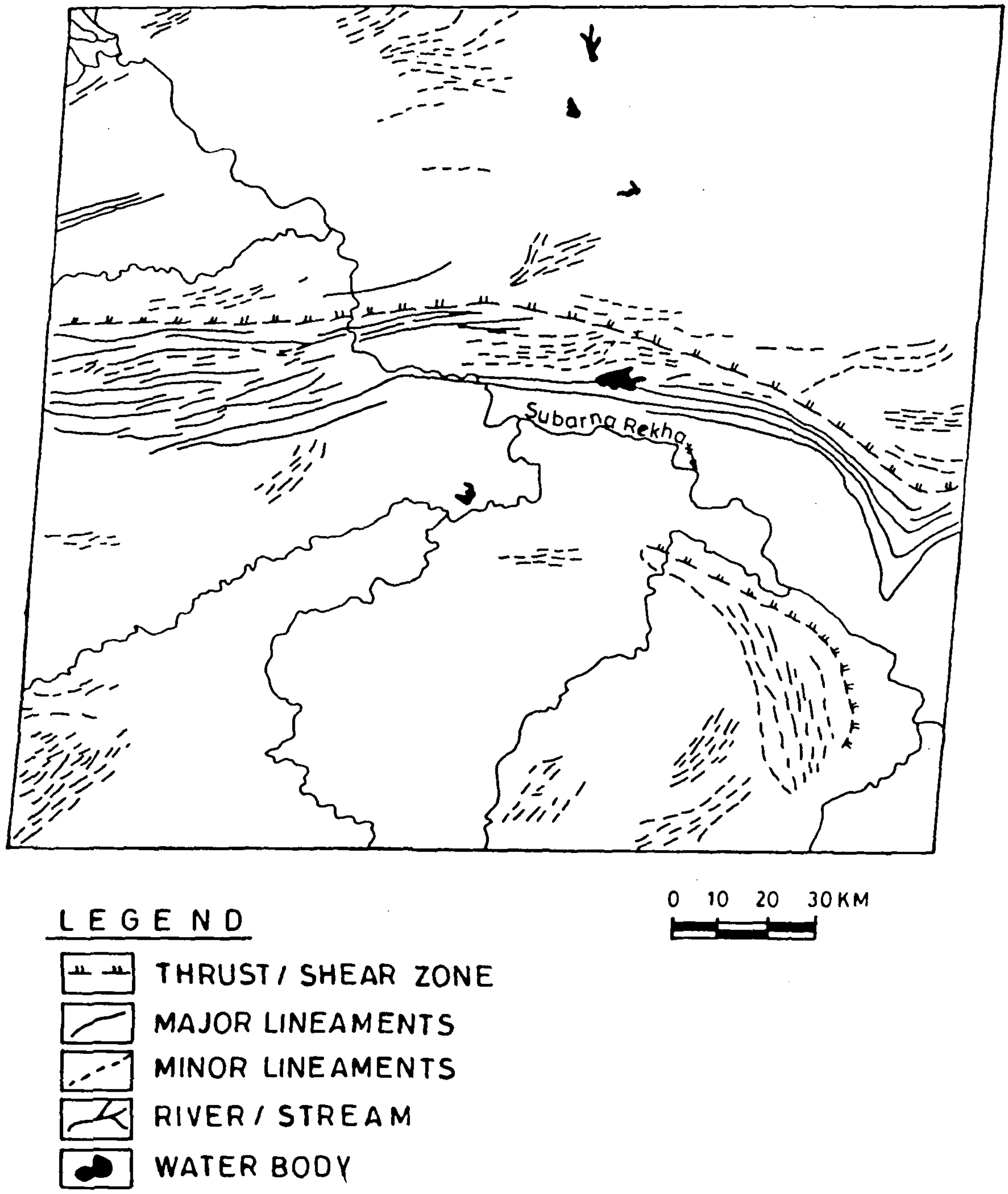


Fig.7: Visual interpretation map of LANDSAT TM (TIR) data.

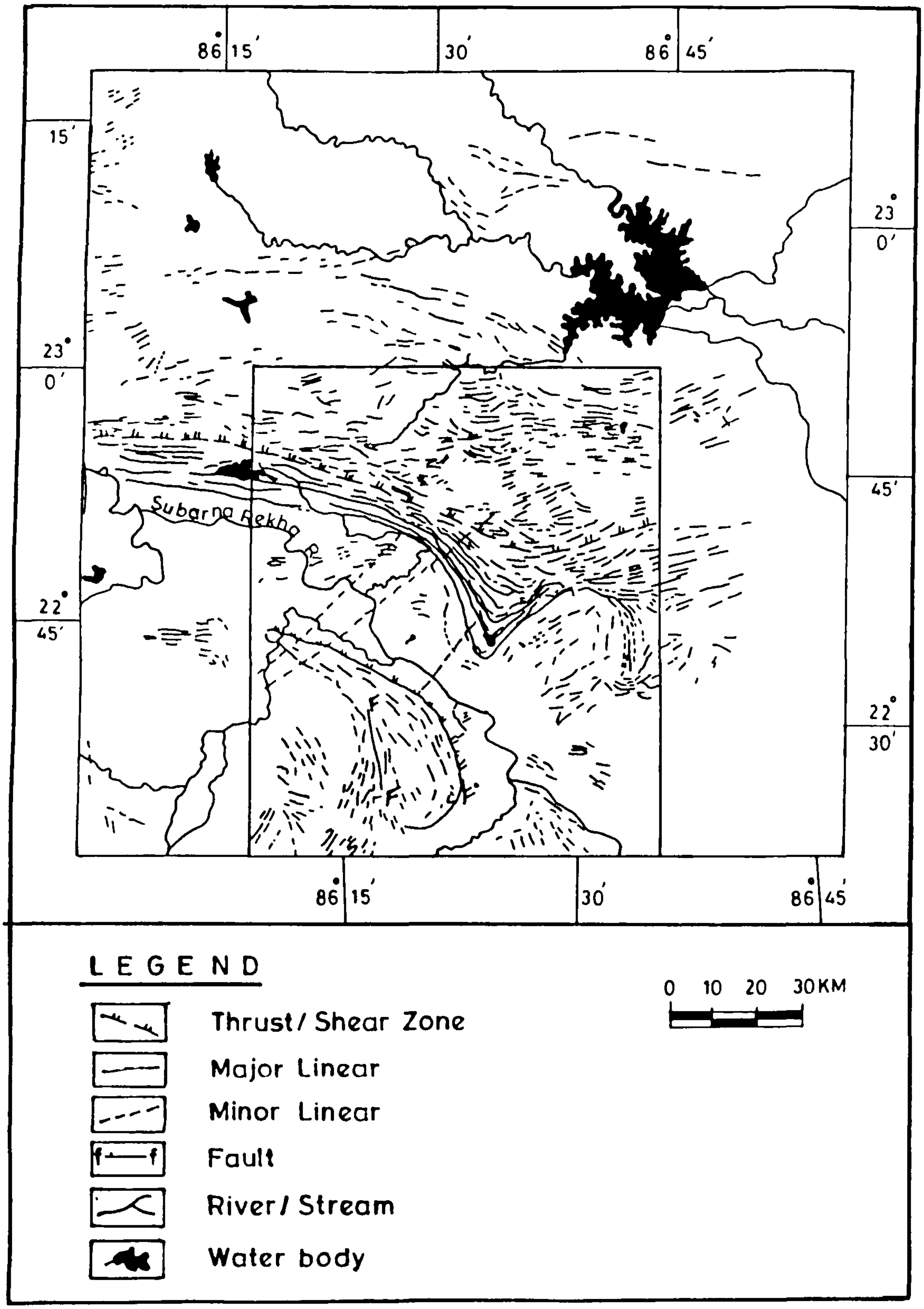


Fig.8: Visual interpretation map of IRS-1A LISS II subscene over the study area.

The direction of most of the linears is E-W, however other linears are aligned NW-SE. Visual interpretation of regional linears was also carried out through MOS-1 VTIR image, and all the major linears were extracted, showing predominently NW-SE and E-W directions. Figure 9 shows the original MOS-1 VTIR (B-1) image over the eastern region including SSZ slightly west to the centre of the scene.

To enhance the regional trends (E-W, NW-SE, NE-SW) and the anomalous patterns of interest, various types of digital image processing, including image transforms (digital filtering) using FFT, directional filters using Sobel operators and convolution techniques using different templates have been attempted over LANDSAT and MOS-1 data over the area of interest, and some of the linears and anomalous patterns could be extracted. Detailed discussion over the lineament extraction is given in the methodology. It has been observed that the digital filtering using FFT and certain directional filters using different templates are useful for automatic extraction of the regional as well as local lineament trends. Directional filtered (E-W) imagery over the eastern region using MOS-1 data (Fig. 9) is shown in Fig. 10(a). Similar directional filters have also been applied for NE-SW and NW-SE linear trends. The final interpretation from those filtered imageries is shown in Fig. 10 (b). Figures 11-12 show the extracted patterns over a part of SSZ as obtained from some of above processing.

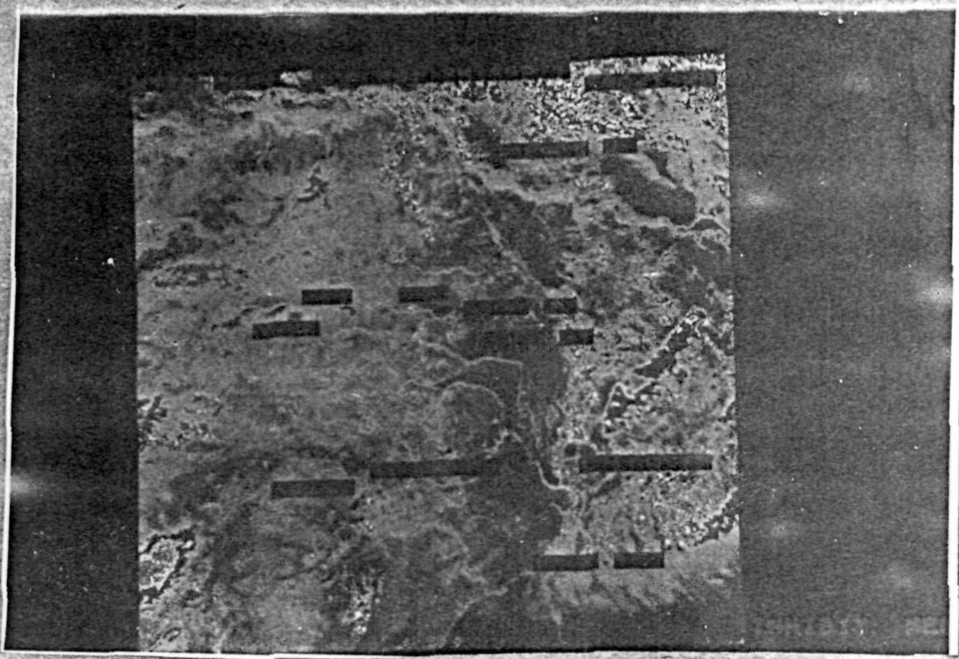


Fig.9: MOS-1 VTIR (B-1) imagery of the eastern region covering SSZ.

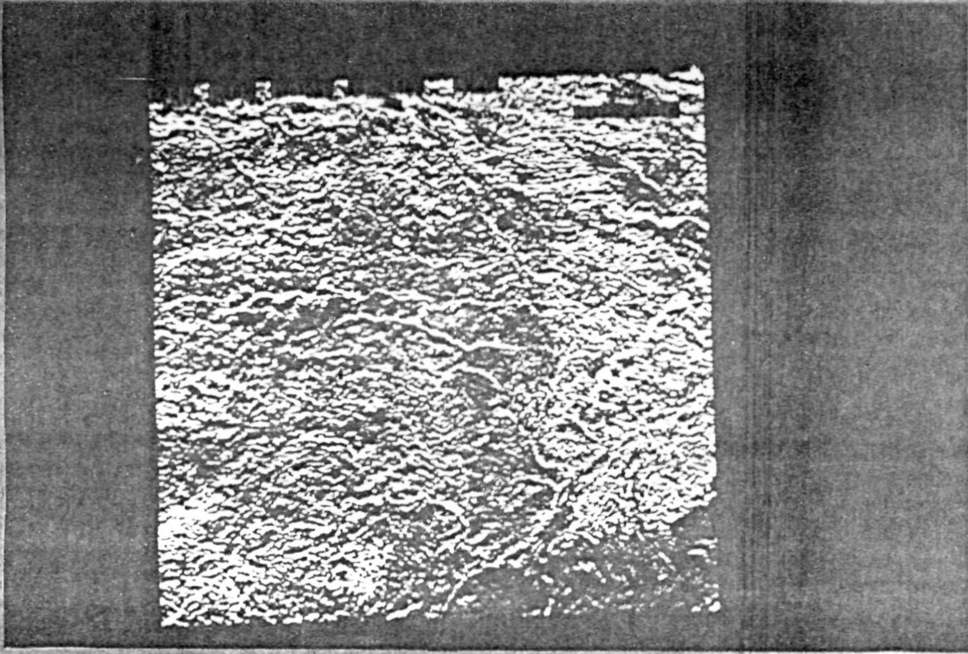


Fig.10(a): Directional filtered (E-W) imagery over the same area.

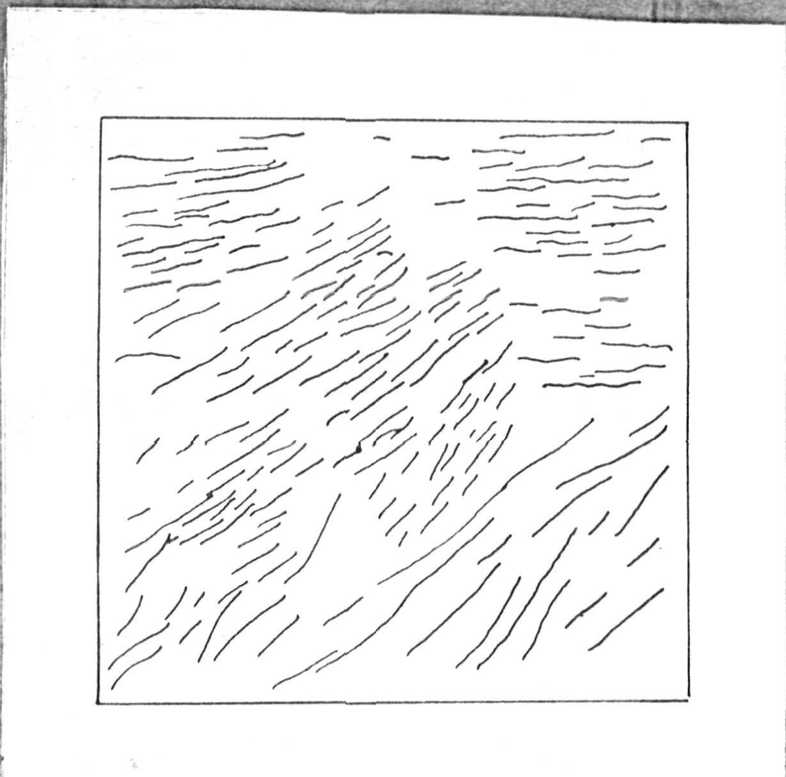
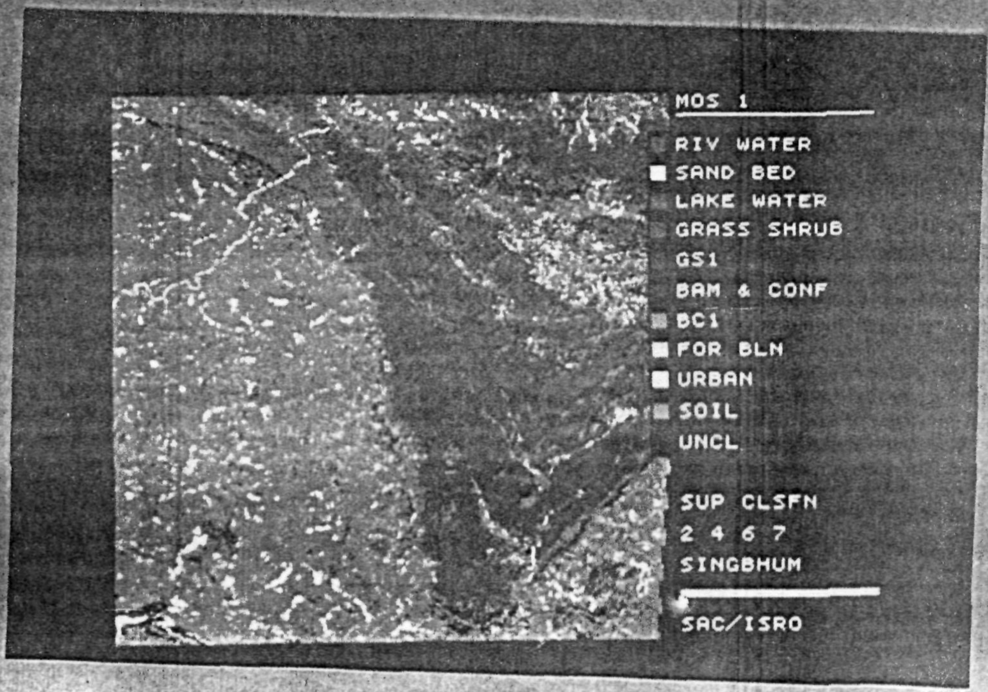


Fig.10(b): Visual interpretation of regional linears from MOS-1 VTIR image.



11(a): Classified image obtained from LANDSAT TM data.

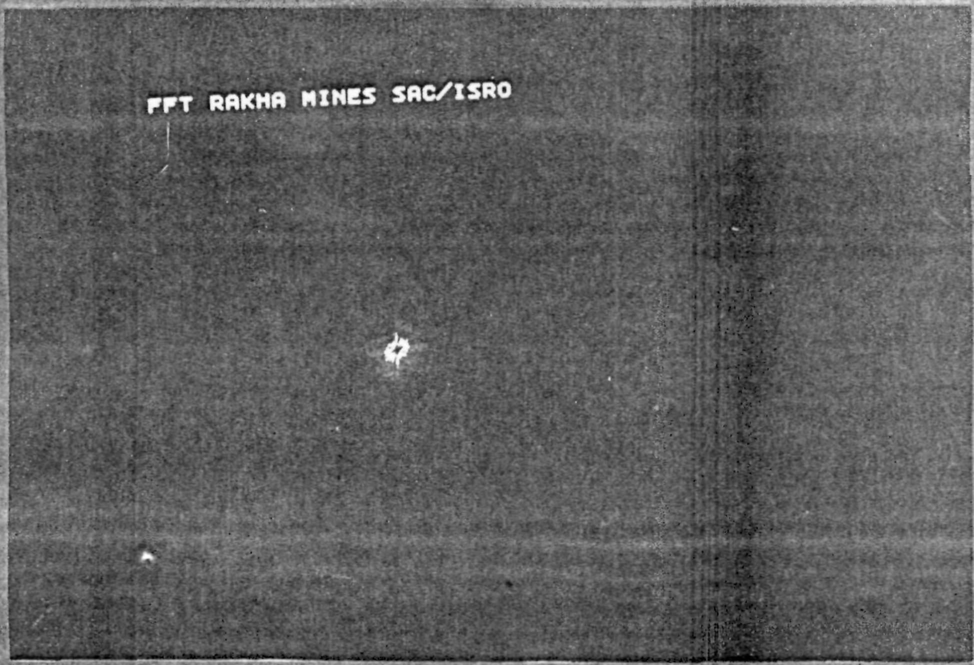


Fig.11(b): Power spectrum of the classified image using FFT.

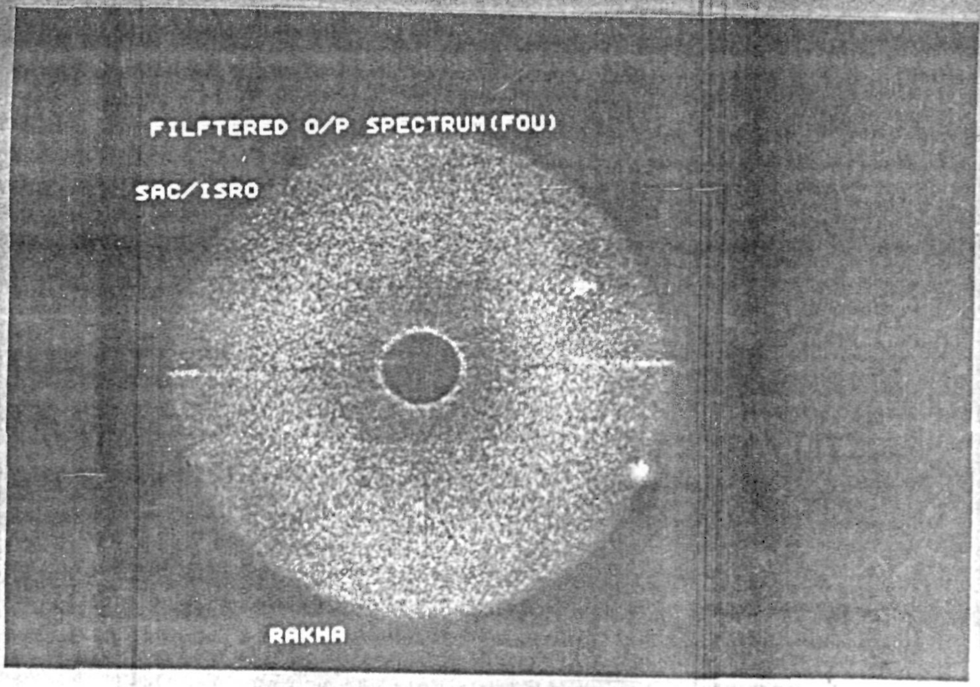


Fig.11(c): Filtering in the frequency domain.

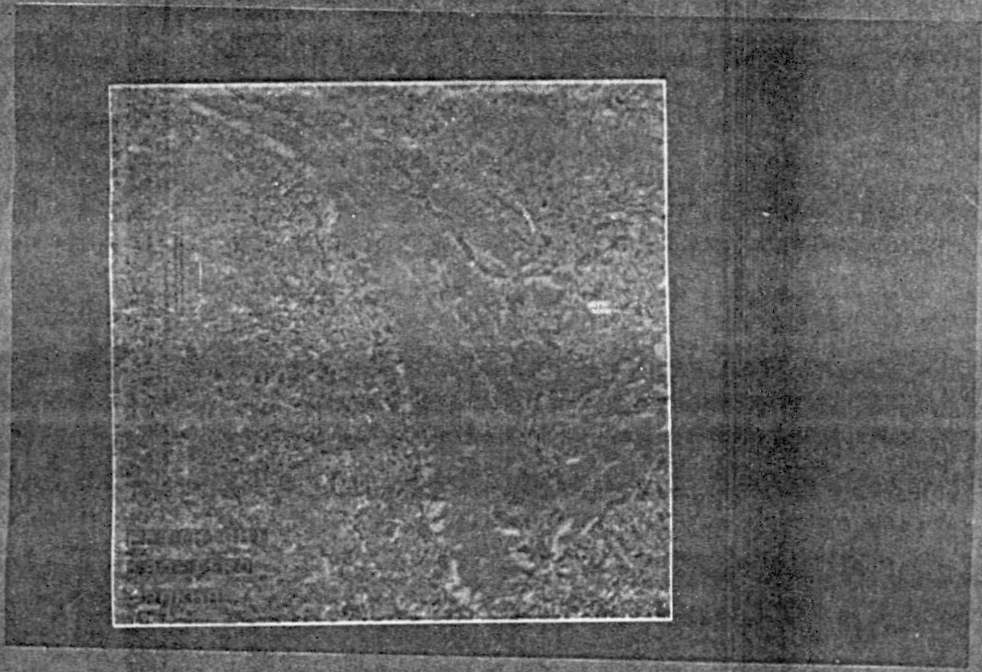


Fig.11(d): Filtered image over a part of study area.

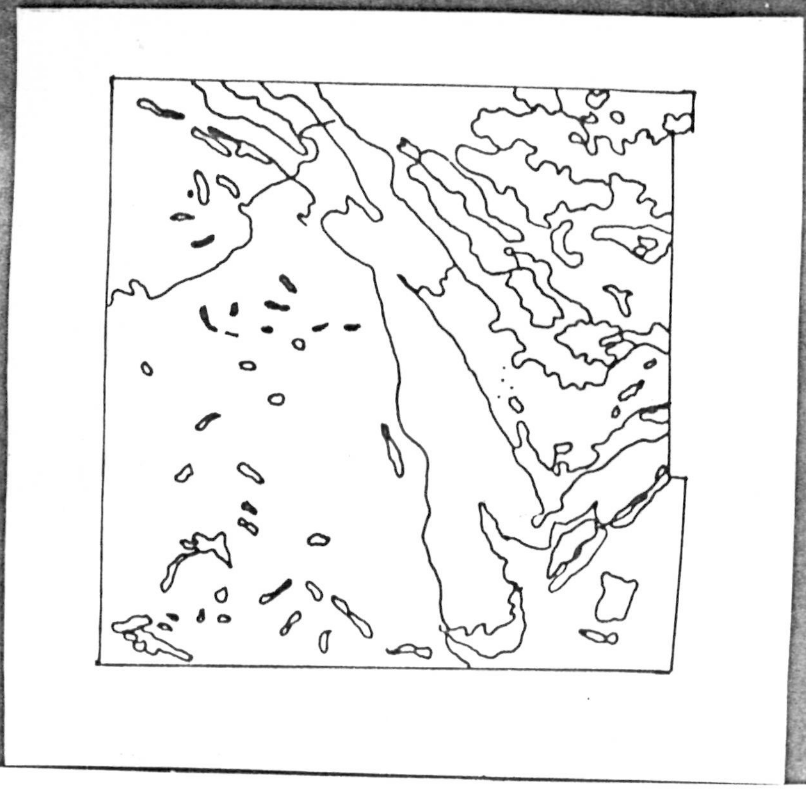


Fig.11(e): Interpreted map over a part of SSZ as obtained from Fig.11(d).

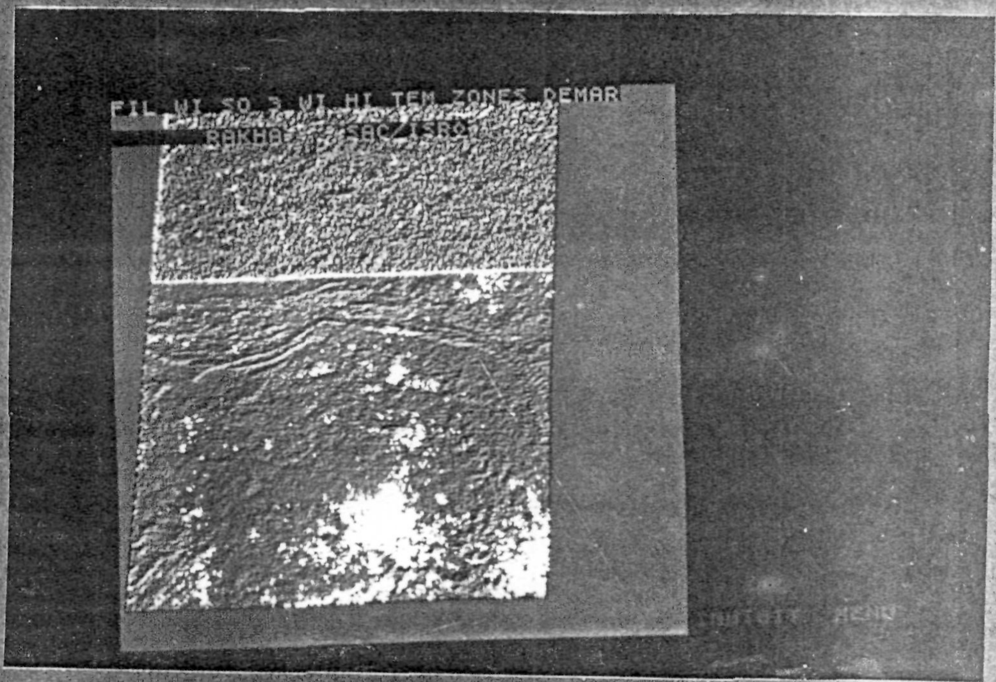


Fig.12: Extracted image using LANDSAT TM (TIR) data over a part of SSZ using Sobel operators.

* The top portion of the area is blurred due to inherent data loss.

Finally, the major trends in SSZ has been found to be E-W, NE-SW, and NW-SE, which collate very well with the earlier studies.

5.4 RELIEF DATA

The study area falls in the Survey Of India toposheet number 73 J, on 1 : 2,50,000 scale. Alluvial slopes and valleys surrounded the mountains. The topography is rugged in the ranges, particularly in the north and south-western part of the study area. A gentle relief is observed in the foothills and alluvial plains, through which Subarnarekha river making its way, in the central part of the area of interest.

There is a chain of ranges, hills and ridges along the shear zone and conspicuously present in the north and south-western part of the area. A maximum elevation of 650 m occurs in the south-western part of the area, alluvial slopes on the south-eastern side descend to an elevation of 100 m or even less at few other places.

6.0 METHODOLOGY

Figure 13 shows the block diagram for the overall approach adopted in this study.

The present study is based on the integrated technique to the different data sets. (Siegal and Gillespie , 1980). In this connection, geological, geophysical and remotely sensed data are used, and an attempt has been made to develop a mathematical model for mineral targeting and lineament extraction. The following steps are involved in the present study :

- Collection of geological information of the area of interest, including mineral/ore occurrence map, geological map, tectonic map etc.
- Collection of geophysical, i.e. gravity and magnetic data over the study area. Preparation of Bouguer anomaly and magnetic anomaly maps.
- Collection and extraction of topographic (relief) data, primarily from Survey Of India toposheets.
- Extraction of LANDSAT MSS digital data from CCTs. Processing of the data for the four bands (bands 4, 5, 6 and 7), generation of ratio images with various combinations and generation of FCC and CRC images.
- Determination of optical densities for all the four bands and six ratios.
- Extraction of linear features visually from IRS-1A LISS II image and LANDSAT TM TIR band image.

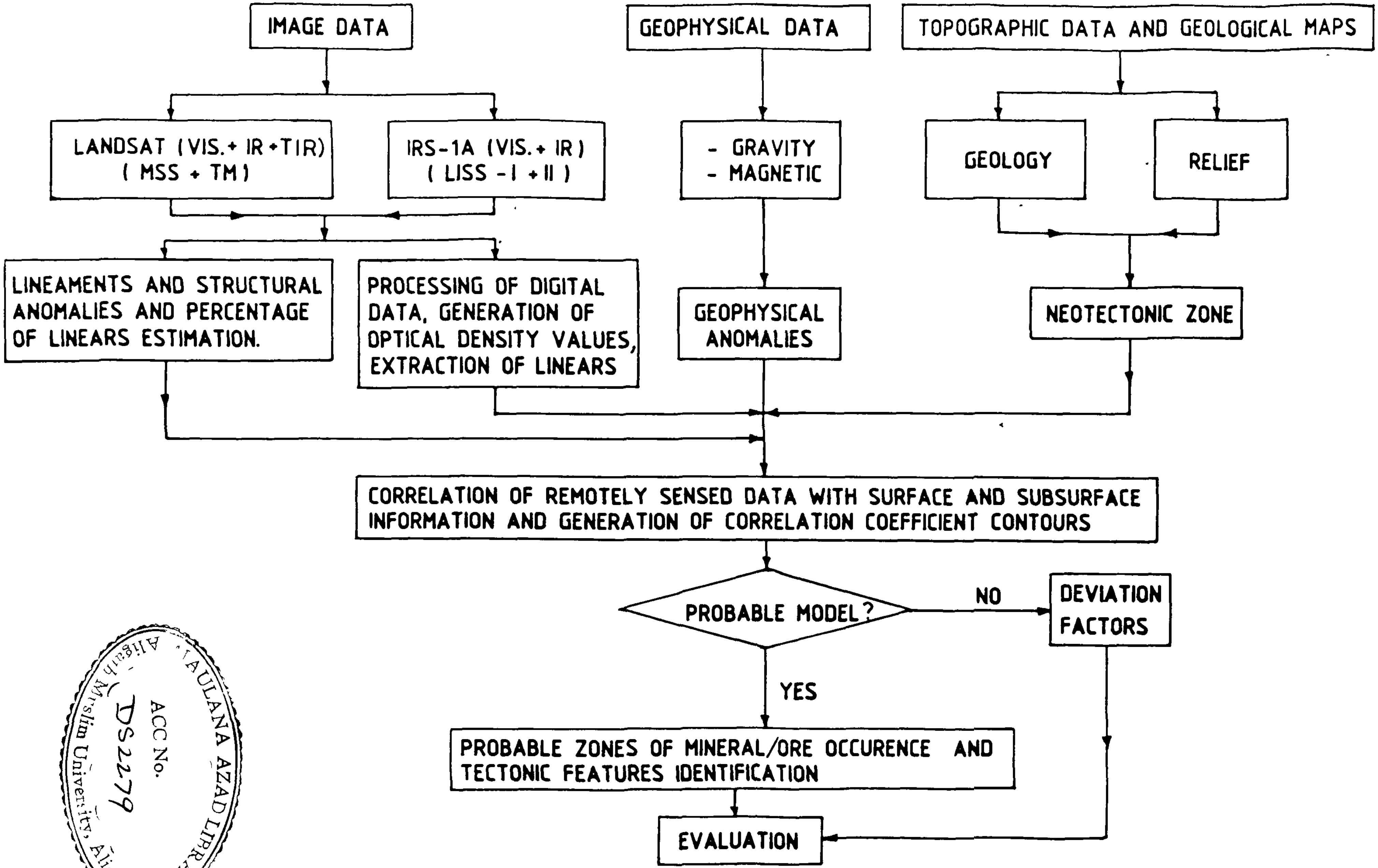


Fig.13: Schematic diagram showing the overall approach adopted for this study.

- Extraction of local and regional linears over the study area through digital processing, applying FFT, convolution and directional filters to LANDSAT MSS and MOS-1 VTIR data (Pratt, 1978).
- Generation of lineament density map over the study area.
- Generation of multiple correlation coefficient contours using optical density (OPD), gravity, magnetic and percentage of linears for selected bands and ratio images.

The gravity data were obtained from Verma et al.(1984) and Bouguer anomaly map was prepared for the study. The map was enlarged to our desired scale and contours were extrapolated with uniform interval of 8 mgals. The study area was divided into twenty four grids of equal dimensions and six equidistant points were chosen in each grid. For each point the nearest contour value was assigned. The contour patterns were studied precisely, and interpreted in terms of gravity highs and lows.

Though, the magnetic data was sparce over the region of interest, but the regional magnetic linears were obtained from available aeromagnetic data. For magnetic data too, the area was divided into twenty four equidimensional grids and for each grid, six equidistant points were chosen and magnetic values were recorded manually. The values were then interpreted in terms of lows and highs.

The linears were extracted visually by IRS-1A LISS II FCC and LANDSAT TM TIR band image. The lineaments are better depicted on IRS-1A LISS II scene, and, therefore, for our study we have selected IRS-1A LISS II image for lineament analysis. The percentage of linears was recorded approximately for each point of all the twenty four grids. The values then were used in generating the areal lineament density contour map shown in Fig. 14.

Digital image processing was carried out using LANDSAT MSS CCT, path-row (139-45) of 15th March, 1986, through DIPIX Image Processing System available at Space Applications Centre (ISRO), Ahmedabad. All the four MSS bands were extracted and studied in relation to their geology, structure, mineral occurrences and optical density values. Figures 15 (a-d) show the output of all the four MSS bands.

The extracted digital data were further processed and six ratio images were obtained using the following band combinations :

ratio no.	MSS band combination
1	4/5
2	4/6
3	4/7
4	5/6
5	5/7
6	6/7

The importance of ratio images rests in the fact that they minimise the first order effects of brigtness variation due to topographic slopes (Sabins, 1978). Rationing

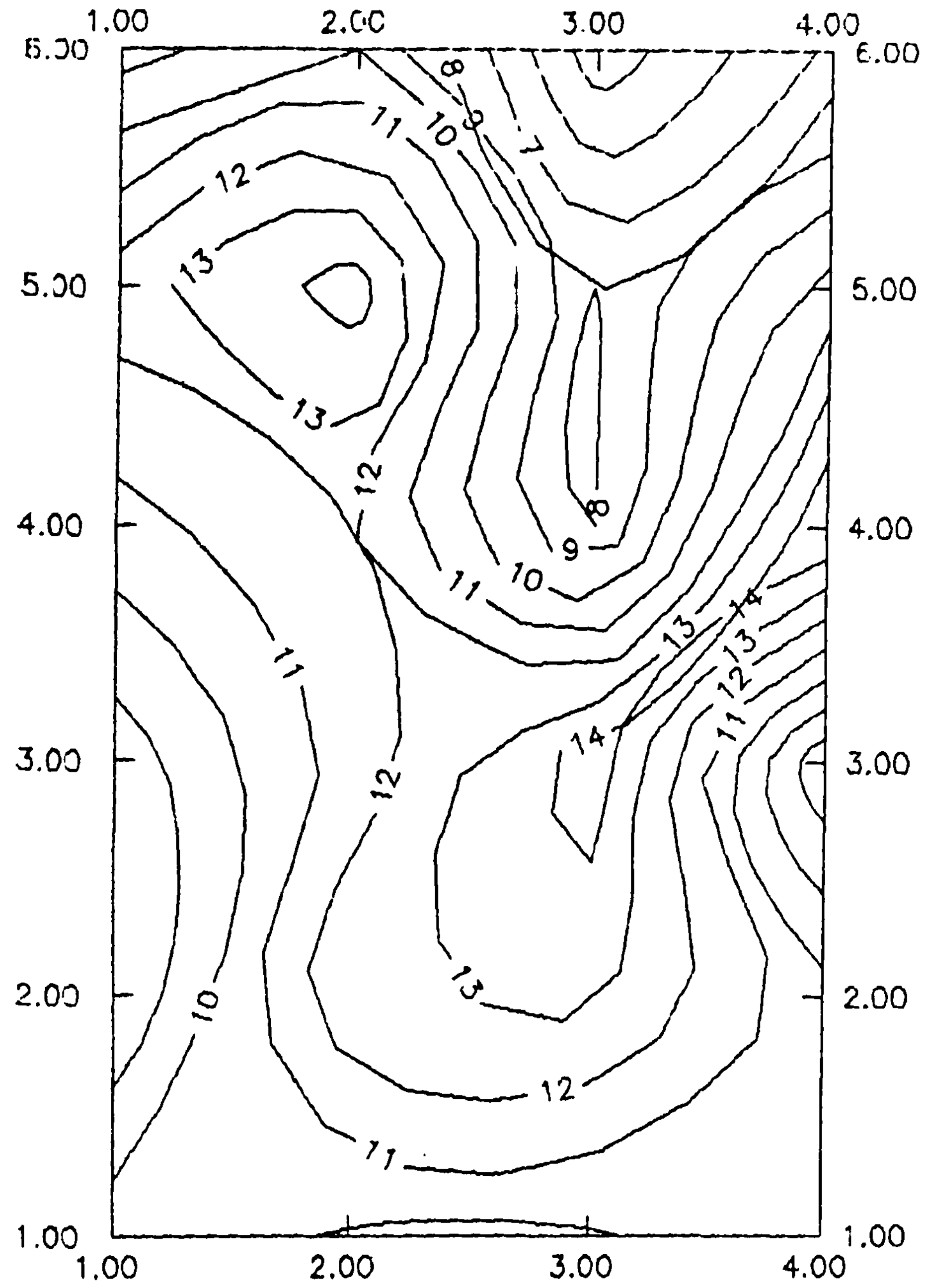


Fig.14: Areal lineament density contour map over the area of interest.

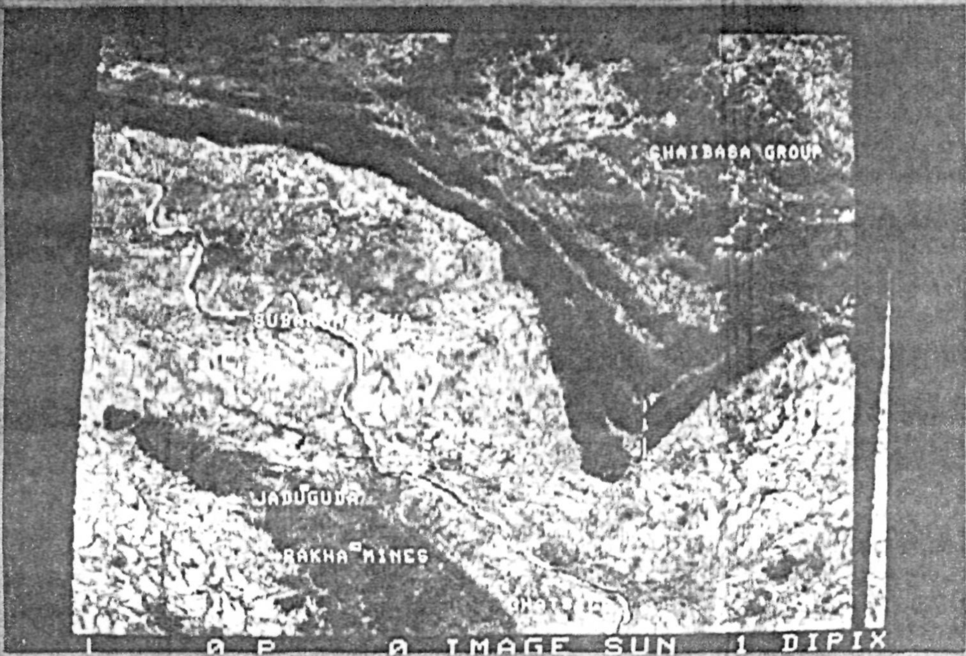


Fig.15(a): Extracted image of the study area as obtained from LANDSAT MSS band 4.

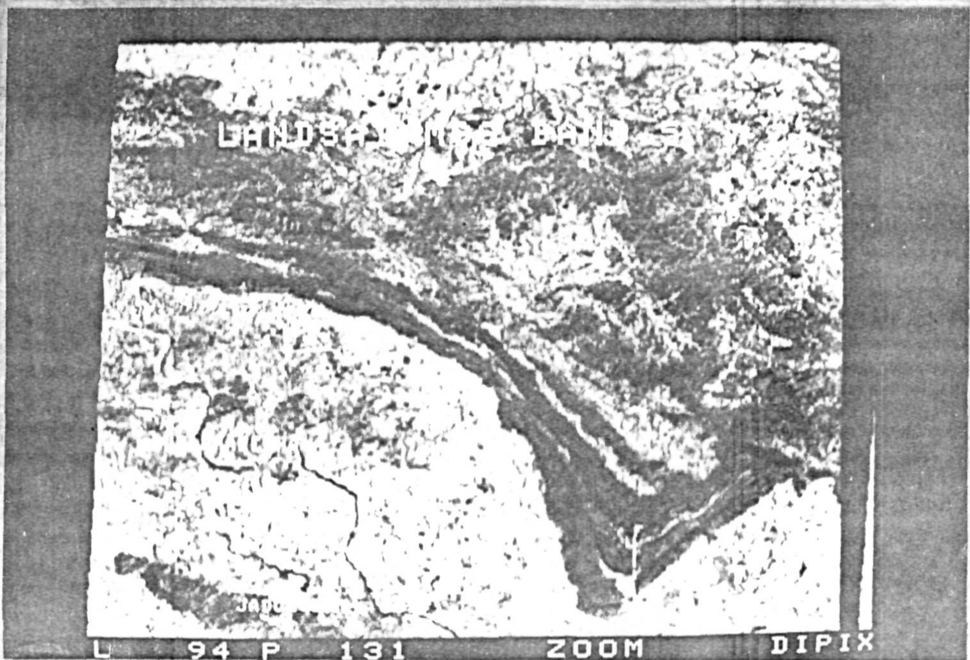


Fig.15(b): Extracted image of the study area as obtained from LANDSAT MSS band 5.

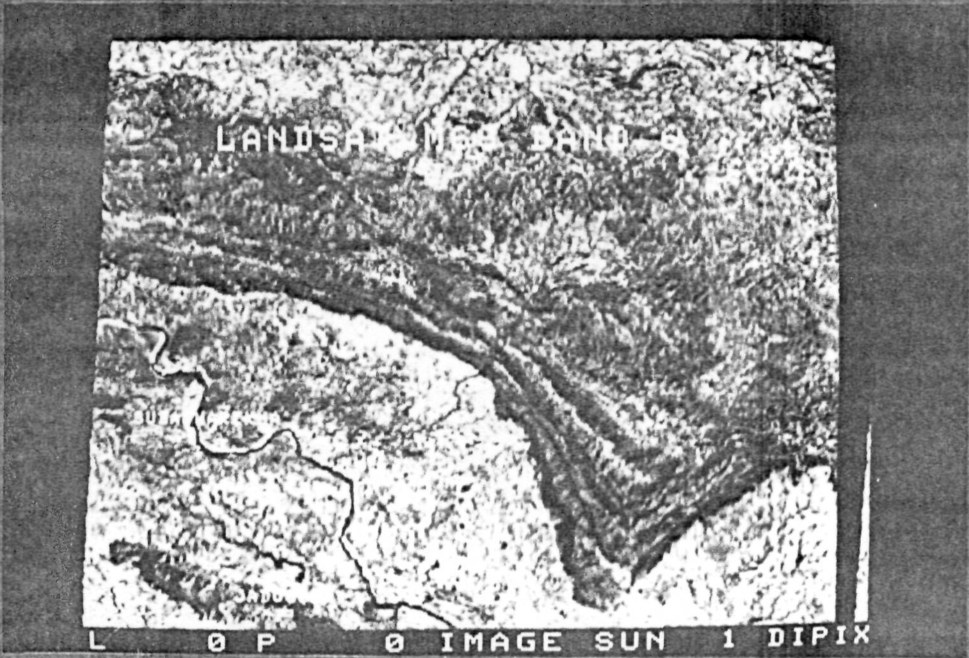


Fig.15(c): Extracted image of the study area as obtained from LANDSAT MSS band 6.

Fig.15(d): Extracted image of the study area as obtained from LANDSAT MSS band 7.

is also useful in enhancing minor differences between materials. Ratio images display the differences between reflectance spectra of bands in one image. They have found to be useful for lithologic discrimination in areas, otherwise lacking contrast. They, sometimes, enhance structure controlled drainage patterns. Figure 16 shows the image generated from ratio 5 (MSS 5/7).

The ratios were studied thoroughly and then few of them were selected depending upon their suitability for our study. Their optical density images were also obtained.

False colour composite (FCC) and colour ratio composite (CRC) were also generated using different bands and ratio combinations and some of their results are shown in Figs. 17 and 18 respectively.

For the extraction of the linears, various filtering techniques were applied to LANDSAT MSS and MOS-1 digital data (Smirnov, 1982). MOS-1 VTIR data were processed to extract the regional lineament patterns, whereas the localised linears over the area of study were obtained by using different filtering techniques over LANDSAT MSS/TM data. Convolution filtering (in some preferred directions) was applied and its results were studied. For extraction of linears, Sobel and FFT were also applied and the final images were obtained, some of them are shown in Figs. 10-12.

A brief diagram showing the major steps for

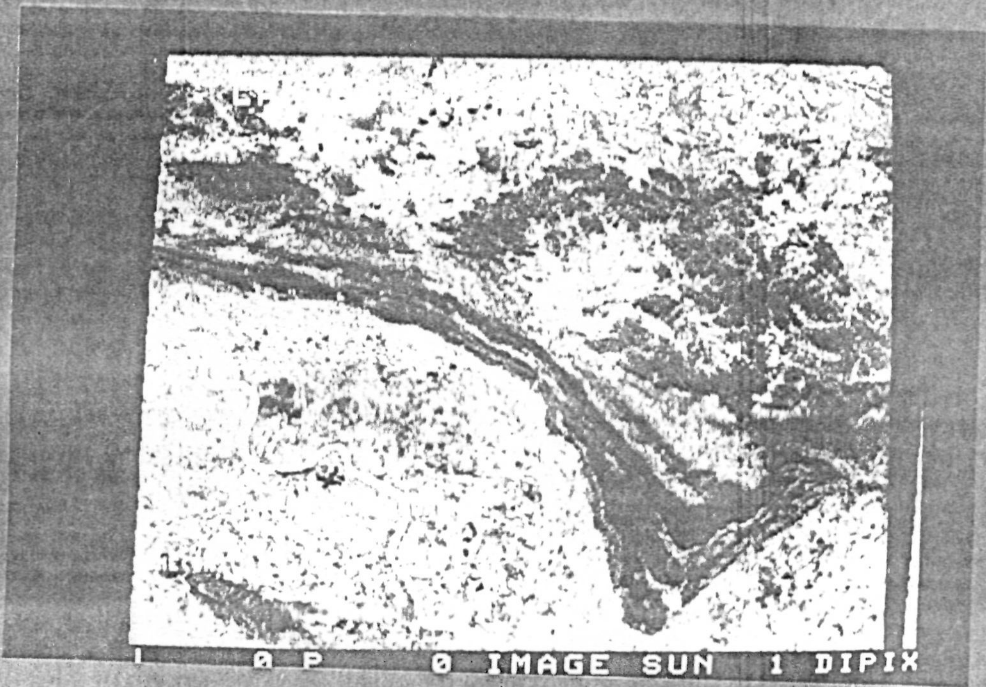


Fig.16: LANDSAT MSS image obtained from ratio 5 (MSS 5/7).

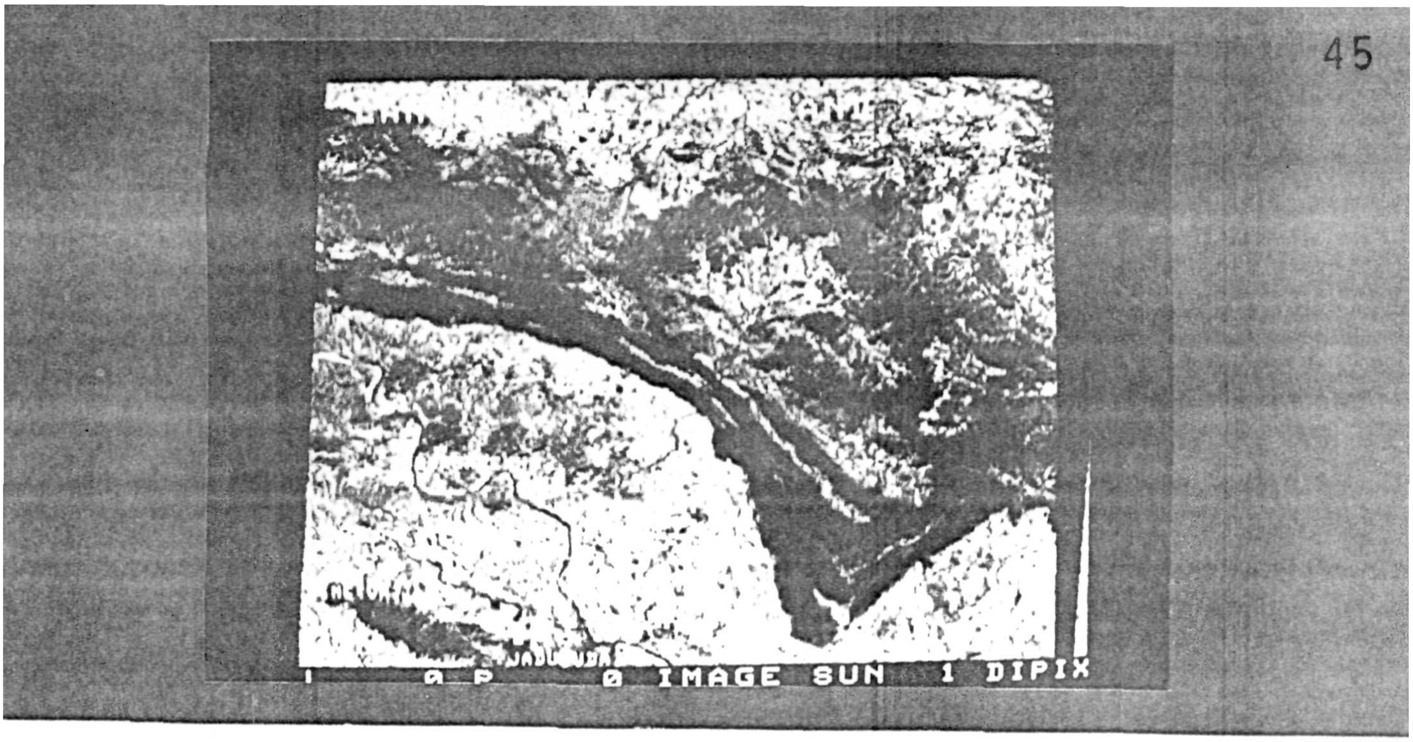


Fig.17: False colour composite (FCC) of LANDSAT MSS data.

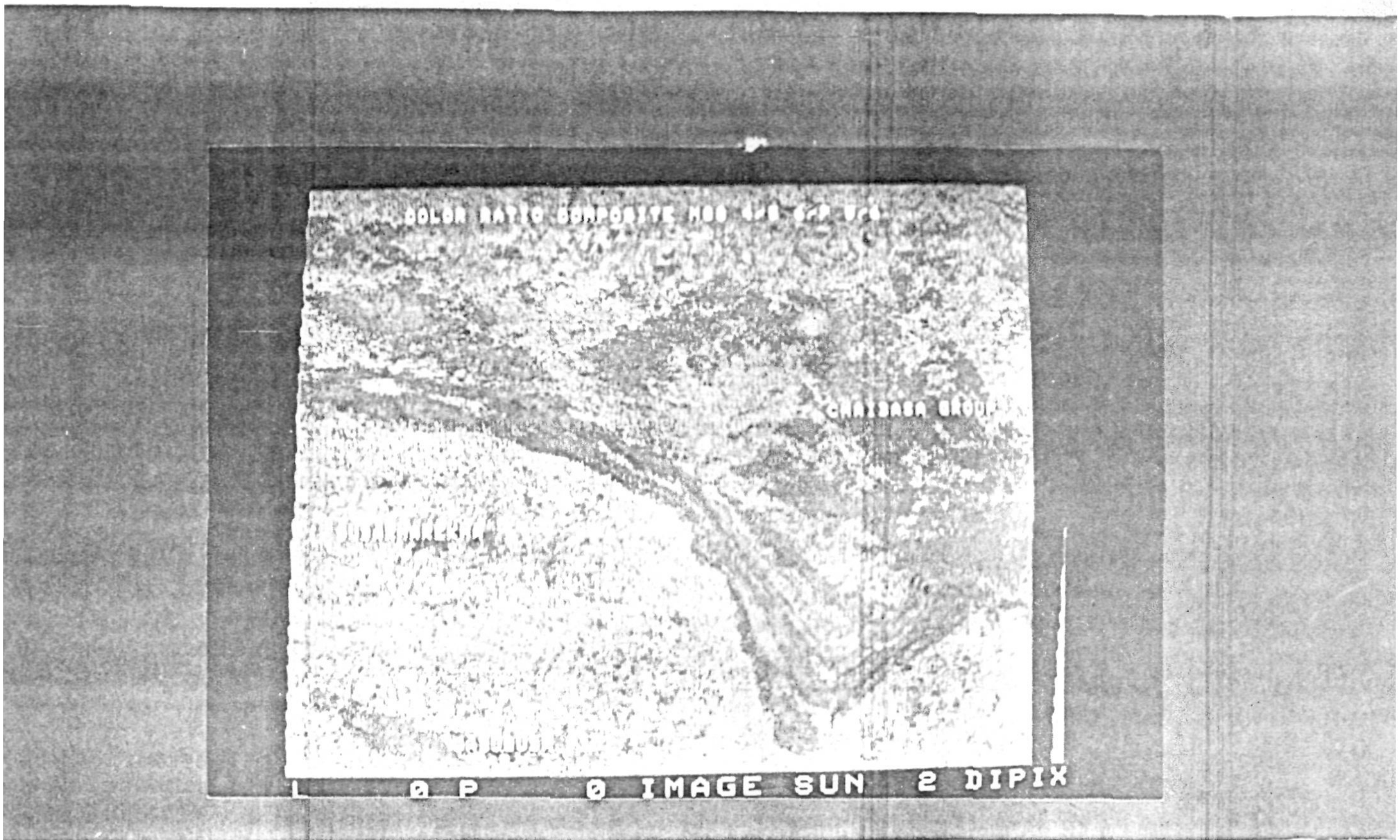


Fig.18: Colour ratio composite (CRC) of LANDSAT MSS data.

lineament extraction using FFT is shown in Fig. 19.

The optical density images were generated for all the four bands and six ratios using a package (developed at Space Applications Centre, Ahmedabad), and their values were used in obtaining multiple as well as bivariate correlation analysis, between different data sets. With the help of geological, geophysical and lineament data along with optical density values, the correlation contour maps were obtained and studied in relation to geology, tectonics and mineral occurrences of the area. Figure 20 shows the optical density image obtained from MSS band 6.

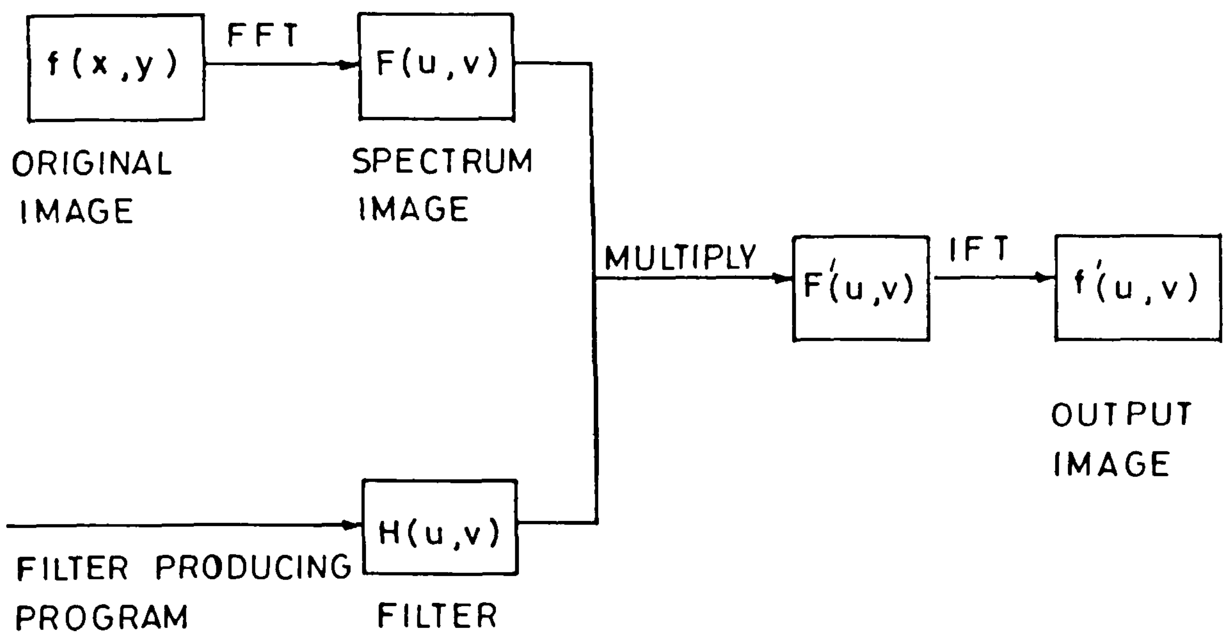


Fig.19: Basic procedure of Fourier filtering.

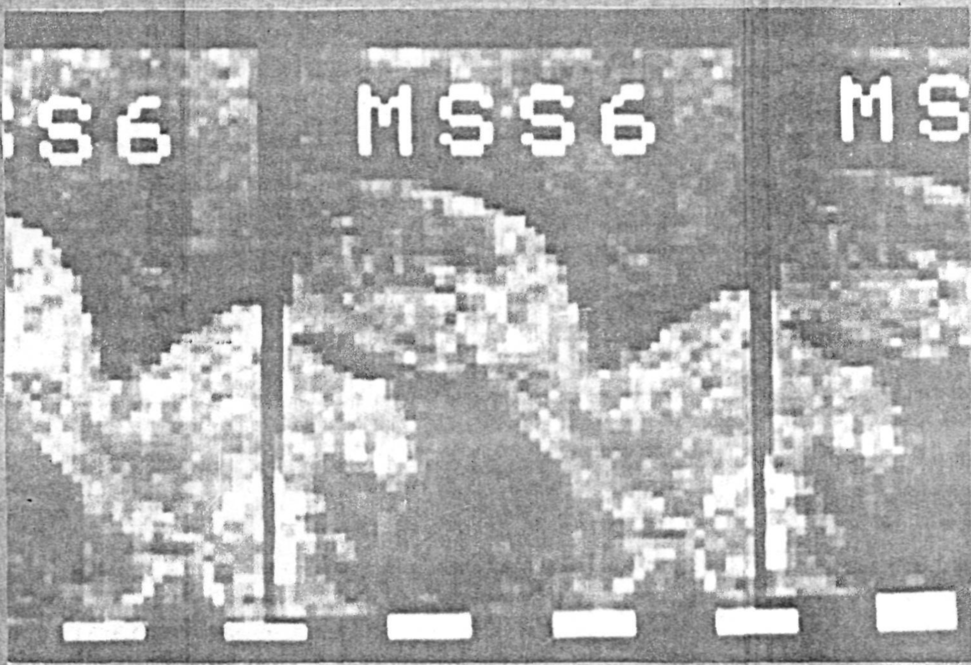


Fig.20: Optical density image of LANDSAT MSS band 6.

6.1 DEVELOPMENT OF MATHEMATICAL MODEL

Model was developed on multiple correlation between remotely sensed data and other geological and geophysical data (Mitra et al., 1985).

INPUT : Optical density, gravity, magnetic, lineament and topographic data.

METHOD : Consider a known metallogenic province and correlate the optical density contours with other information. The probable reason may be the possible change in the soil texture, outcrop patterns, structural anomalies and vegetation patterns due to the existance of subsurface structures. Then varify the model with unknown mineral/ore province provided all other related geological/geophysical information are available.

OUTPUT : To infer the structural parameters of another anomalous zone and compare with actual value and explain the cause of variation, if any.

6.2 VALIDITY OF THE APPROACH

The method is tested firstly over the existing occurrences of various mineral/ore. Next, validity of this approach is tested for other probable metallogenic provinces over the whole area of interest and accordingly new probable zones have been identified for further geological/geophysical survey.

THE MODEL

G = gravity value M = magnetic value

Ld = lineament density h = elevation

OPD = optical density

Assuming optical density as a function of all other independant variables. e.g. G, M, ... etc.

Then, $OPD \propto f(G, M, Ld, h)$

Or, $OPD = K_1G + K_2M + K_3Ld + K_4h + K_5$

Where $K_1, \ldots, K_5$ are constants.

7.0 RESULTS AND DISCUSSION

Figures 7 and 8 show the visually interpreted lineament patterns and other geological features over the SSZ using LANDSAT TM and IRS-1A LISS II imageries respectively. The IRS-1A LISS II data seems to be more helpful in depicting major lineament and other anomalous patterns over SSZ and Rakha mines area. However, the major lineament trends dominating in this area are E-W, NW-SE, and NE-SW as seen in those interpreted maps.

All the four MSS bands were extracted and are shown in Figs. 15 (a-d). It is observed that MSS bands 5 and 7 give maximum information and are best suited for the interpretation of geologic and geomorphic features.

It seems that digital processing using various image transforms may help in extraction of regional linears and anomalous patterns in two ways namely, it automatizes the whole procedure of interpretation which is highly time-consuming and secondly, it removes the human bias/ error from the final interpretation. The imageries corresponding to different steps of a Fourier Transformed filtering and their interpretation are shown in Figs. 11 (a-e). Also, the extracted image over a large part of SSZ using LANDSAT TM Thermal IR data after applying filtering with Sobel operators is shown in Fig. 12. It can be clearly seen that certain new linear and anomalous patterns which were not very clear in the visually interpreted images (Figs. 7 and

8) are depicted sharply in those filtered imageries which help in identifying the global as well as local trends.

As far as the mineral occurences are concerned, Rakha mines and its surrounding areas seem to be highly economical zones from mineral/ore exploration point of view. Accordingly, bivariate analyses have been carried out over SSZ and Rakha mines and their correlation coefficients have been analysed in details. Tables II and III show the correlation coefficients obtained for different grids using optical density, gravity, magnetic and lineament data. Similar studies have been carried out with other geophysical data and optical density combinations, as well. It has been finally observed that MSS band 5 (0.6-0.7 μm) and MSS band 7 (0.8-1.1 μm) as well as three ratios (MSS 4/6, MSS 5/6, MSS 6/7) are highly sensitive for correlation coefficient analysis. This result particularly supports the findings of the earlier study by Mitra et al. (1985) for hydrocarbon-bearing structure delineation over a part of Cambay basin. The difference which should be marked here is that the Cambay basin was mainly covered by alluvial sediments whereas in the Rakha mines and its surrounding areas, the lithologic units and the relevent outcrops/vegetation are exposed.

Accordingly, multiple regression analyses were attempted using the above OPD combinations with other geophysical data. The areal density of lineaments were plotted as shown in Fig. 14 and used as one of the inputs.

TABLE-II

Bivariate correlation coefficient values between OPD (MSS 5) and gravity data.

Grid no	Correlation coefficient
1	0.68
2	0.72
3	0.45
4	0.72
5	0.62
6	0.52
7	0.64
8	0.71
9	0.84
10	0.70
11	-0.68
12	0.54
13	0.25
14	-0.30
15	0.41
16	0.40
17	-0.27
18	0.28
19	0.23
20	0.18
21	-0.39
22	0.75
23	0.71
24	-0.69

TABLE-III

Bivariate correlation coefficient values between OPD (MSS 7) and magnetic data.

Grid no.	Correlation coefficient
1	0.32
2	0.73
3	-0.58
4	-0.45
5	-0.41
6	-0.38
7	-0.79
8	0.30
9	-0.66
10	0.51
11	0.67
12	0.26
13	-0.47
14	-0.64
15	0.48
16	-0.50
17	-0.27
18	0.49
19	0.42
20	-0.67
21	-0.43
22	0.70
23	0.73
24	-0.46

The multiple correlation contours are marked by high values, particularly for OPD band 5 and ratios 4 (MSS 5/6) and 6 (MSS 6/7). Tables IV, V and VI show the corresponding multiple correlation coefficients for OPD (MSS 5) and (ratio MSS 5/6 and 6/7). Figures 21-24 show the corresponding correlation coefficient contours for MSS 5, MSS 7 ratio 4 and ratio 6 respectively. It can be easily identified that Rakha mines area, falling mainly in grid numbers 13 and 14 are showing high multiple correlation values varying between 0.8 to 0.9. Some of the multiple regression equations are given below over the Rakha mines area.

Equation of the fitted curve is OPD = -27.52682+ -0.27406 G + 0.00864 M+ -0.00726 Ld -----(1)

Multiple correlation coefficient = 0.94 **(for MSS 5)**

Equation of the fitted curve is OPD = 16.8422+ -0.01345 G + -0.00647 M+ 0.04376 h ------(2)

Multiple correlation coefficient = 0.86 **(for MSS 6/7)**

With the output of similar models, we can probably now explore the possibility of finding new probable zones of mineral/ore occurrences in the overall area of SSZ and the following areas falling under grid nos. 7, 10, 22 and 23 (latitudes 22° 47'- 22° 53'; 22° 42'-22° 47'; 22° 20'-22° 26' and longitudes 86° 30'-86° 37'; 86° 18'-86° 30'; 86° 20'-86° 37' approximately) respectively seems to be of special

TABLE-IV

Multiple correlation coefficient values between OPD (MSS 5), gravity, magnetic and lineament data.

Grid no.	Correlation coefficient
1	0.69
2	0.74
3	0.82
4	0.80
5	0.62
6	0.59
7	0.89
8	0.84
9	0.79
10	0.81
11	0.85
12	0.72
13	0.50
14	0.90
15	0.85
16	0.67
17	0.49
18	0.51
19	0.74
20	0.81
21	0.78
22	0.87
23	0.81
24	0.79

TABLE-V

Multiple correlation coefficient values between OPD (ratio 4 MSS 5/6), gravity, magnetic and lineament data

Grid no.	Correlation coefficient
1	0.83
2	0.80
3	0.79
4	0.81
5	0.68
6	0.83
7	0.87
8	0.47
9	0.79
10	0.78
11	0.85
12	0.46
13	0.80
14	0.98
15	0.59
16	0.73
17	0.37
18	0.28
19	0.85
20	0.87
21	0.83
22	0.87
23	0.95
24	0.82

TABLE-VI

Multiple correlation coefficient values between OPD (ratio 6, MSS 6/7), gravity, magnetic and lineament data.

Grid no.	**Correlation coefficient**
1	0.76
2	0.80
3	0.79
4	0.73
5	0.67
6	0.77
7	0.82
8	0.77
9	0.85
10	0.83
11	0.87
12	0.66
13	0.88
14	0.98
15	0.84
16	0.45
17	0.38
18	0.40
19	0.80
20	0.83
21	0.77
22	0.88
23	0.79
24	0.71

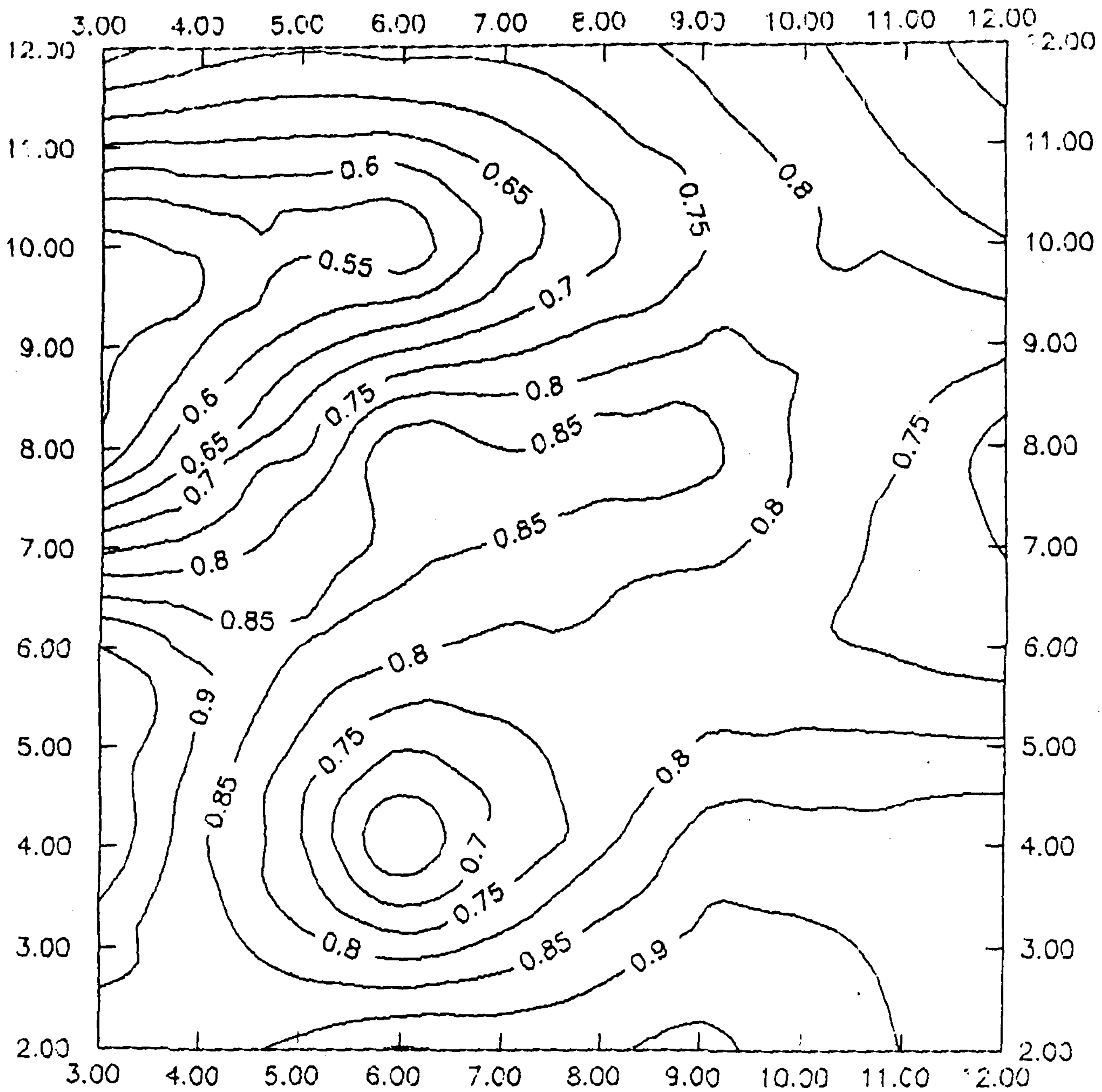


Fig.21: Isolines of multiple correlation coefficient for for optical density (MSS band 5), gravity, magnetic and percentage of linears.

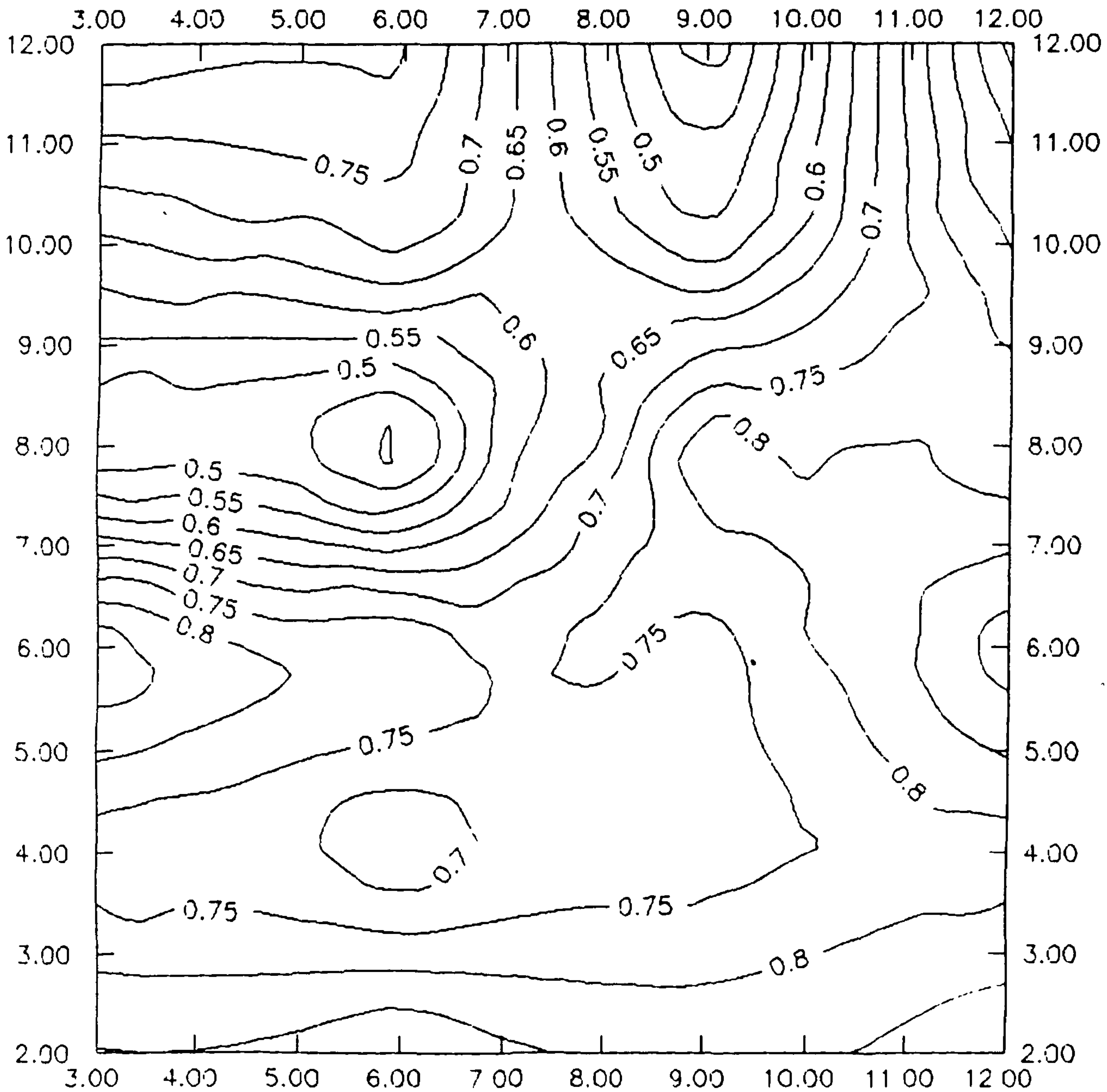


Fig.22: Isolines of multiple correlation coefficient for optical density (MSS band 7), gravity, magnetic and percentage of linears respectively over the SSZ.

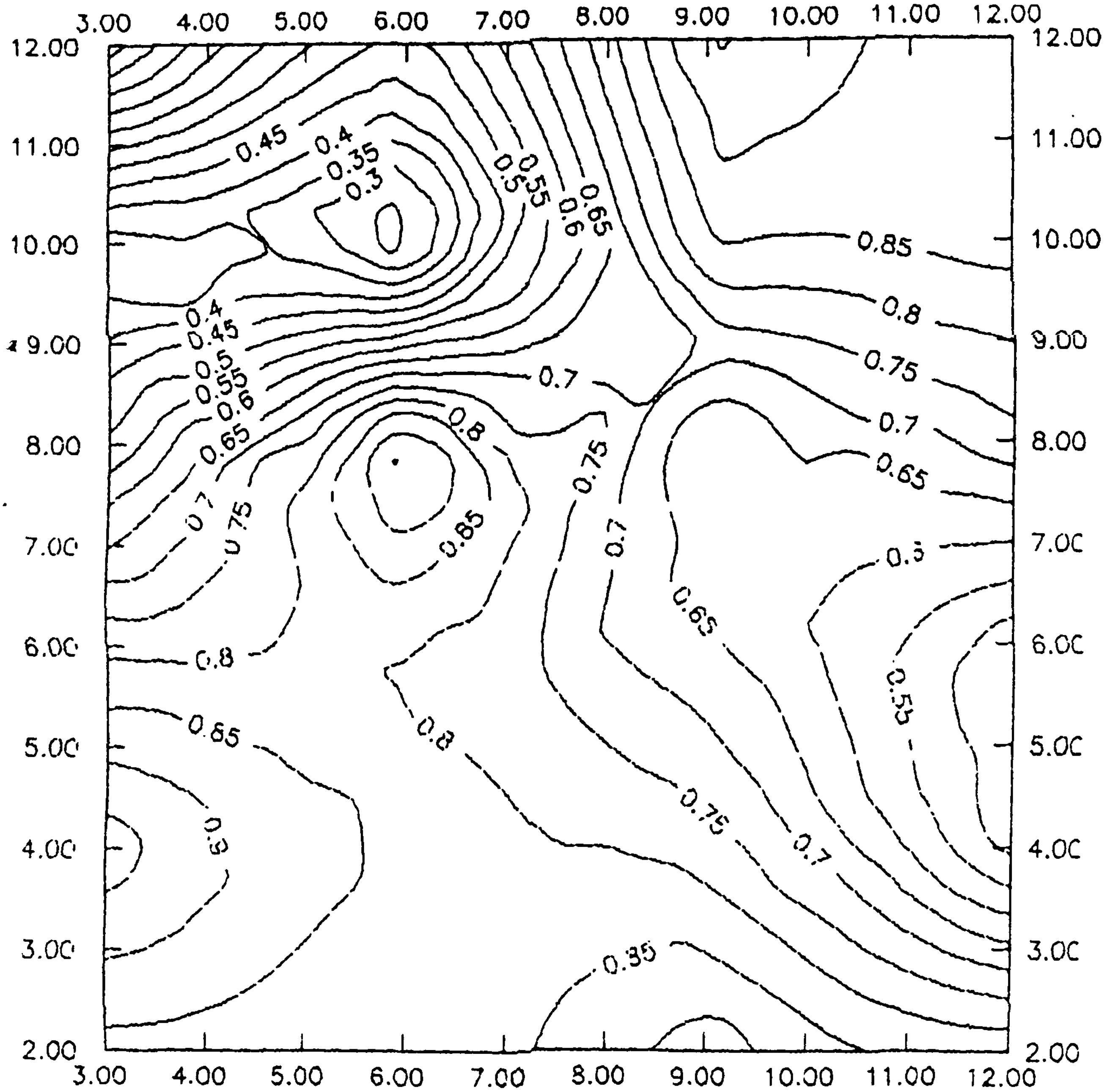


Fig.23: Isolines of multiple correlation coefficient for optical density (ratio 4, MSS 5/6), gravity, magnetic and percentage of linears respectively over the SSZ.

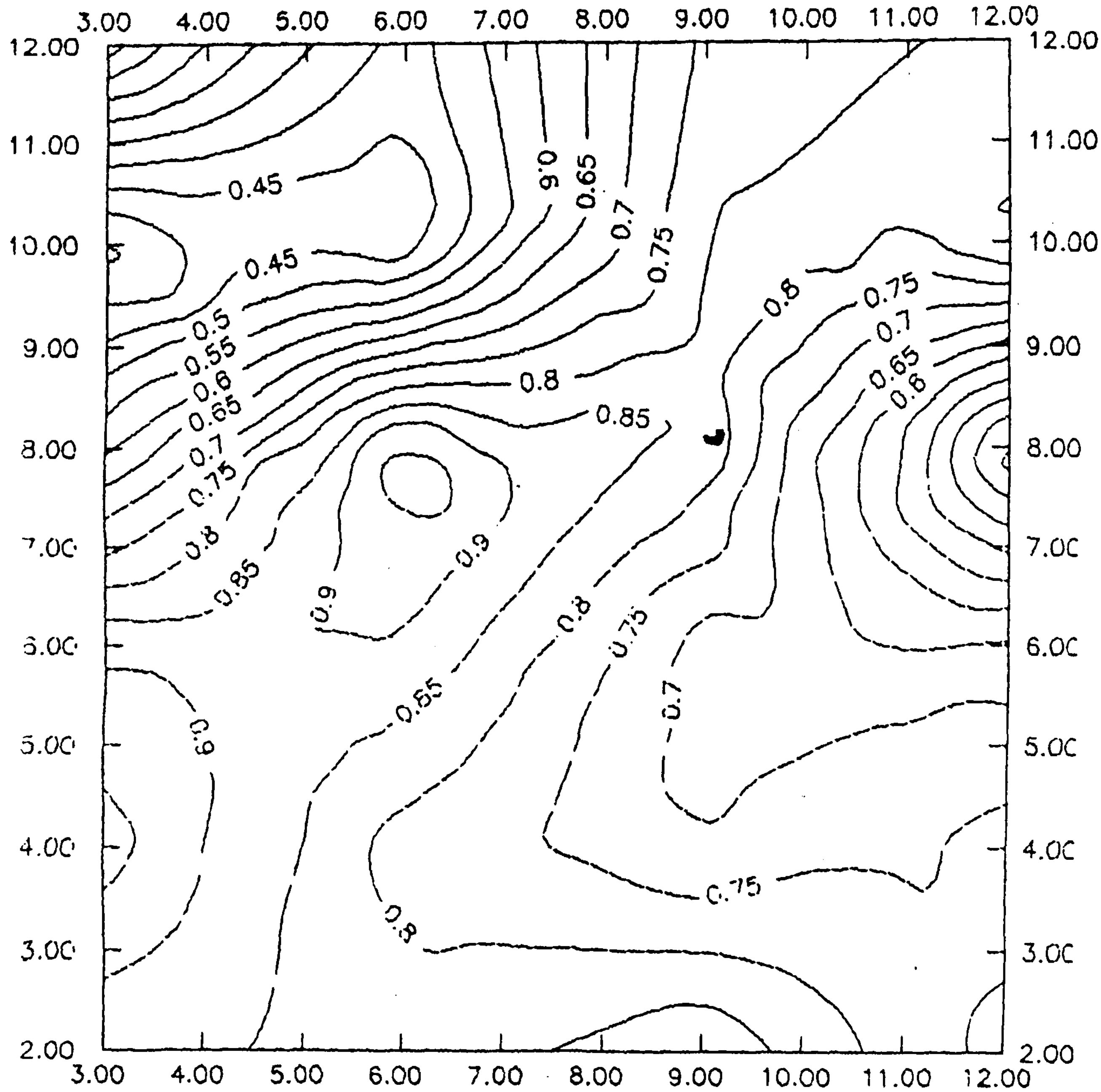


Fig.24: Isolines of multiple correlation coefficient for optical density (ratio 6, MSS 6/7), gravity, magnetic and percentage of linears respectively over the SSZ.

attention. However, checking the geology and geomorphology and tectonic patterns, it seems that areas falling within latitudes and longitudes range 22° 47'-22° 53'N to 86° 30'-86° 37'E and 22° 21'-22° 25'N to 86° 25'-86° 37'E are of special interest for which geological/geophysical study should be carried out for their exploration with economic viability. Figure 25 shows the probable mineralised zones over the area of interest as obtained from the present study.

Now, coming to the history of the tectonic set-up of the area as observed from Sarkar and Chakraborty (1982), that more than one orogenic belt were existed prominently during the complex tectonic built-up over the SSZ and the maximum shear was developed over lattitudes 22° 38'-22° 47' and longitudes 86° 27'-86° 35' (grid nos. 10 and 11). Very interestingly, a sharp correlation contour values of the order of 0.75-0.8 has been marked using OPD MSS 5 and MSS 5/6 (Figs. 21 and 23). The multiple correlation values are much less (of the order of 0.5-0.6) in the smooth zones near Jamshedpur (lat. 22° 50'-22° 55' and long. 86° 15'-86° 20') and also in other tectonically less active zones. This is clearly in confirmation with the tectonic studies made by Sarkar and Charkraborty (1982) and Banerjee (1981).

Finally, it can be said that the quantitative integrated approach is highly useful in delineating the mineralised zones as well as in depicting the tectonic activities over the area of interest (Kowalik and Glenn,1987). Though, Gupta (1992) has qualitatively attempted

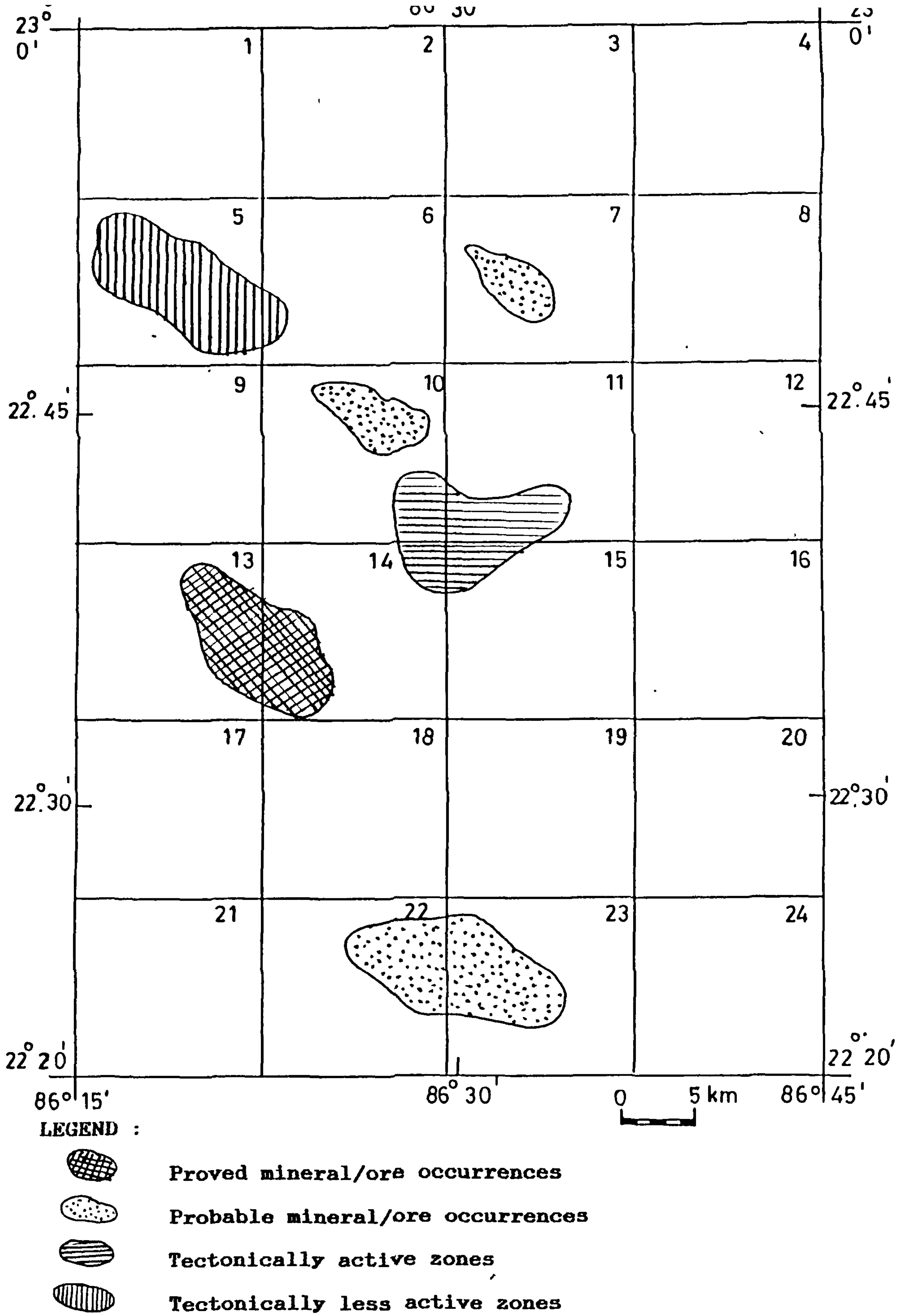


Fig.25: Probable mineralised/tectonically active zones over the area of interest as obtained from the present study.

similar approach earlier, the quantitatively developed model may be used in pinpointing the different zones of study. Gupta (1992) has finally proposed to attempt similar studies in his recent observation. Also, lineament extraction using digital filters seems to be more authentic and devoid of human errors which may be helpful in delineating the linear patterns and anomalous zones in the area of study.

8.0 CONCLUSIONS

From the present study the following conclusions can be drawn :

- As per the study, MSS bands 5 and 7 are more informative and useful. Certain ratios e.g. MSS 4/6, MSS 5/6, and MSS 6/7 are also useful and show good correlations. MSS 5/6 and MSS 6/7 are quite useful even compared to the original bands and show high correlation values between geophysical and remotely sensed data.
- Multiple correlation is useful for validation as well as prediction of the probable mineral/ore occurences in a mineralized belt.
- Integrated approach adopted in quantitative fashion seems to be quite interesting and useful for mineral targeting as well as tectonic information.
- The major linear trends in SSZ as obtained by visual interpretation and the subsequent digital filtering techniques are E-W, NE-SW, and NW-SE.
- Application of digital filtering techniques seems to be quite useful and devoid of errors generated from human interpretation. Also, they are faster compared to routine interpretation techniques.
- Interpretation of tectonically active zones from remote sensing integration technique is a new development and has to be further tested for new areas.

- Linear relationship has been attempted in the present study, but exponantial/inverse relationship should also be attempted for future studies.
- Though zones of economic importance has been identified and confirmed by the present technique, the newly located probable zones identified through the present studies should also be tested with other geophysical data and methods.
- For accurate prediction of different mineral/ore bodies, high resolution data set e.g. SPOT/aerial MSS may be more helpful.
- Aerial/satellite TIR data should also be used for regional geothermal anomaly prediction, which may be related to the detection of occurences of radioactive minerals in this region.
- Validity of this integrated approach can further be explored/tested for other mineralized belts of the Indian shield, in relation to their economic and tectonic importance.

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APPENDIX-A

(Channel specifications for different satellite sensors)

LANDSAT MSS

channel no.	wavelength range (μm)
4	0.5-0.6
5	0.6-0.7
6	0.7-0.8
7	0.8-1.1

LANDSAT TM

channel no.	wavelength range (μm)
1	0.45-0.52
2	0.52-0.60
3	0.63-0.69
4	0.76-0.90
5	1.55-1.75
6	10.4-12.5
7	2.08-2.35

IRS-1A LISS I & II

channel no.	wavelength range (μm)
1	0.45-0.52
2	0.52-0.59
3	0.62-0.68
4	0.77-0.86

MOS-1 VTIR

channel no.	wavelength range (μm)
1	0.5-0.7
2	6.0-7.0
3	10.5-11.5
4	11.5-12.5

APPENDIX-B

List of software packages used for data extraction and digital processing.

REFOBIL : This package reformats the LANDSAT MSS data (interleaved by line) in the image format, after correction due to aspect and skew angle (related geometric correction).

OPTDEN : This package generates the optical density values from a digital number pixel by pixel.

TMRFMT : This package reformats the LANDSAT TM data (BIL format) after correction due to aspect and skew angle (related geometric correction).

IRS UCCT-LOAD : This package reformats the IRS LISS II data (BIL format) available in IIPS.

BIVCR : A data analysis approach which defines two dimensional relationship and correlation between two variables for effective discrimination.

MULTR : It is a data analysis approach which makes use of multi-dimensional inter-relationships and correlations within the data for effective discrimination.

REGRN : It is a data analysis approach, which uses two dimensional as well as multidimensional data sets and brings out relationship between them through regression.

BARATIO : This package processes digital multispectral data such that for each pixel the value for one band is divided by that of another.

FFTAN : This package makes use of Fast Fourier Transform and brings out additional information in an extracted image.

CONFIL : It enhances the major and minor linears of an extracted image in some preffered directions.

SOBOPT : This package uses a 3X3 or 5X5 templates and highlights subdued information on digital MSS data.